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ENCYCLOPÆDIA METROPOLITANA;

OR,

UNIVERSAL DICTIONARY OF KNOWLEDGE,

On an Original Plan:

COMPRISING THE TWOFOLD ADVANTAGE OF

A PHILOSOPHICAL AND AN ALPHABETICAL ARRANGEMENT,

WITH APPROPRIATE ENGRAVINGS.

EDITED BY

THE REV. EDWARD SMEDLEY, M.A.,
LATE FELLOW OF SIDNEY COLLEGE, CAMBRIDGE;

THE REV. HUGH JAMES ROSE, B.D.,
PRINCIPAL OF KING'S COLLEGE, LONDON;
AND
THE REV. HENRY JOHN ROSE, B.D.,
LATE FELLOW OF ST. JOHN'S COLLEGE, CAMBRIDGE.

VOLUME IV.

[Mixed Sciences, Vol. 2.]

LONDON:
B. FELLOWES; F. AND J. RIVINGTON; DUNCAN AND MALCOLM; SUTTABY AND CO.; E. HODGSON; J. DOWDING;
G. LAWFORD; J. M. RICHARDSON; J. BOHN; T. ALLMAN; J. BAIN; S. HODGSON; F. C. WESTLEY; L. A. LEWIS;
T. HODGES; AND H. WASHBOURNE; ALSO J. H. PARKER, AND T. LAYCOCK, OXFORD;
AND J. AND J. J. DEIGHTON, CAMBRIDGE.

1845.

399. d. 8.

BIBLIOTHECA·BODLEIANA

LONDON:—PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET.

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ENCYCLOPÆDIA METROPOLITANA;

OR, THE

UNIVERSAL DICTIONARY OF KNOWLEDGE.

Second Division.

ELECTRO-MAGNETISM.

lectro-
gnetism

1. **Electro-Magnetism** is that science which has for its object the investigation of the relation which subsists between Magnetism and Electricity. The discovery of such a relation is of very recent date, and the science itself can only be considered as in the earliest state of infancy.

§ I. *Brief outline of the history of the science.*

line of
history.

It was for many years suspected that there existed a strong analogy, if not a complete identity, between the electric and magnetic fluids, and various attempts were made to establish such relation on satisfactory principles. It was known, for instance, that lightning destroyed and reversed the polarity of magnetised needles, and that it produced a magnetic power in pieces of steel which had not before any such action. Now lightning and electricity have been long known to be identical; consequently, electricity ought to produce similar effects to lightning on magnetic and simple steel bars; but the attempts which were made to discover a satisfactory proof of this action, by means of the electric apparatus, were not attended with success; at least all that was effected in this way amounted only to communicating the magnetic property to steel bars, but without the experimenter being able to predict in what directions the poles would lie, and therefore was little more than might be produced by a blow, by twisting, and various other means. It was indeed stated that the magnetism was more fully developed when the shock was passed through the needle transversely, than when it passed lengthwise; but still no definite conclusions could be drawn from the experiments.

History.

Philosophers having thus failed of tracing the analogy between the electric and magnetic fluids, by means of the electrical apparatus, had next recourse to the galvanic battery, which was known to possess electrical properties. Of these experiments, those of Ritter are the only ones of any importance. He stated that he had succeeded, by placing a louis d'or in contact with the extremities of a galvanic circuit, in giving to it a positive and negative electric pole, which remained after it had been in contact with other metals; he also magnetised a gold needle by means of the galvanic battery, and seems to have had some obscure ideas of electric terrestrial poles at right angles to the magnetic poles. These experiments, however, were never much regarded, and the relation between the two fluids seemed still to remain doubtful.

Soon after the time that Ritter made his experiments, Professor Oersted, of Copenhagen, published a work, (1807) in which the subject was again resumed, and the hypothesis brought forward, which ultimately conducted him to a successful result.

After describing some analogies between magnetism and electricity, he arrives at this conclusion, viz. that, "In galvanism the force is more latent than in electricity, and still more so in magnetism than in galvanism; it is necessary therefore, to try whether electricity, in its latent state, will not affect the magnetic needle." It is extraordinary, after this idea had once been formed, that means were not taken by the author to submit it to the test of experiment, or if he did submit it, that he had not discovered at the time, the relation he was in search of; yet such was the case, for, from this time to 1820, we hear no further on the subject; but, in the course of the latter year, Mr. Oersted's attention seems to have been again called to the subject: he placed a magnetic needle within the influence of a wire, connecting the extremities of a voltaic battery; and which was now, for the first time, observed to deviate in different directions, and in different degrees, according to the relative situation of the wire and needle. Subsequent experiments proved, that the wire, of whatever metal it was composed, became, during the time the battery was in action, magnetic, and that it affected a magnetic needle through glass, and every other non-conducting body; but that it had no action whatever on a needle, similarly suspended, that was not magnetic.

This discovery opened a new field for philosophical inquiry: notices of Mr. Oersted's experiments were transmitted to Paris, London, and to the several German universities, and, immediately, the most distinguished philosophers of Europe were engaged in the pursuit of this novel and interesting science. In France, the experiments were repeated and extended by MM. Biot, Arago, and Ampere; in Germany, by Professors Rive, Seebeck, Moll, and others, whose names will occur in the following pages; and in England, by Sir Humphry Davy, Professor Cumming, Mr. Faraday, and Mr. Barlow; the three former of whom had for their object to trace the relation between the two sciences of electricity and magnetism, and that of the latter, to reduce the laws of action to the principles of mathematics.

2. In the first instance, it was conceived that the greater the power of the battery, or the machine by which the electricity was excited, the greater would be the effects produced on the magnetised needle; and, accordingly, scarcely any attempted experiments, who had not at command a powerful galvanic apparatus. After some time, however, it appears that great tension of the electric fluid was not only unnecessary, but injurious to the effect produced; and that the most active power was found to proceed from single plates of considerable surface; and even single plates of very small dimensions were found more efficient than larger plates in high combination. In fact, the exhibition of the electro-magnetic effect on the needle, was soon reduced to such a state, that Professor Cumming constructed, on this principle, a galvanometer, which exhibits the existence of electricity, when in so low a state as to be inappreciable with the gold-leaf electrometer, and other delicate instruments proposed for this purpose; and thus a power, which had remained hidden for so many years, and which, after it had been discovered, was so difficult to exhibit, is all at once, as it were, become one of the most delicate tests of the existence, and measurer of the quantity of electricity in bodies under experiment.

3. Up to this period the attention of philosophers had been directed to the examination of the amount of the disturbance which the magnetic needle experienced on the approach of the galvanic wire; to the means of exciting magnetism in steel bars; to the representation of magnets by the galvanic wire under different forms; to the action of galvanic wires on each other; and, consequently to the nature of the force by which these effects were produced. Professor Oersted, who had made the discovery, and who was wholly indebted for his success to the preconceived theory he had entertained of the nature of electric action, conceived the force to proceed from what he denominated the *conflict of the electricities*, proceeding from the opposite extremities of the battery. M. Ampere, on the other hand, attributed the peculiarities of action, to the electric current passing along the wire, and assumed, that magnets owed their peculiar properties to currents of electricity perpetually circulating about their axis. Professor Cumming and Mr. Barlow, without attempting to explain the mechanical means by which this mysterious power is brought into action, and, independent of each other, deduced that all the phenomena which a magnetic needle exhibits in the vicinity of a galvanic wire, might be explained, by assuming that every particle in the wire acts on those in the needle according to a tangential direction, and that every known fact might be illustrated by this hypothesis. The latter went still further, he demonstrated by experiments, which we shall detail, that if this tangential power was conceived to vary inversely as the square of the distance of the particles in the wire and needle from each other, that not only all the facts alluded to might be illustrated, but that they might be computed, and that the results agreed numerically with experiment.

4. Prior to this, however, Mr. Faraday, of the Royal Institution, had made a most interesting discovery; namely, that the nature of the force was such, that if a galvanic wire be freely suspended over the pole of a magnet, and the fluid passed through the wire, the latter will commence a rapid rotation about the magnet; and, on the contrary, the wire being fixed, and the magnet free, the latter will revolve about the former. This curious fact pointed out most distinctly, that the force, whatever it might be, was totally different from any that had yet come under the contemplation of philosophers, for no known natural force was competent to the production of a motion of rotation.

The results of these curious experiments having been transmitted by the author to M. Ampere, he, in his turn, succeeded in causing the magnet to revolve about its own axis; and lastly, Mr. Barlow completed the set of rotatory experiments, by causing the wire also to revolve on its axis.

5. In this state of the science, every fact seemed to have been exhausted; the laws of disturbance and of rotation had been reduced to mathematical laws, and the effect of every new combination might not only be predicted as to direction, but computed as to quantity. At this time, however, some new facts were discovered by Professor Seebeck, of Berlin, not in respect to any new laws of action, but to a different process for exciting the electro-magnetic power, which was by the application of heat to the union of two dissimilar metals; this again opened a new field for investigation, and much that has been elicited on this head, is due to Professor Cumming, whose labours have been as unceasing as the resources of his genius appear to be inexhaustible. He has examined, by means of the delicate instrument to which we have alluded, the numerical ratio, between the electrical powers of the different metals in contact, and has furnished some valuable tables of this description, to which we shall have to refer as we proceed. This has been distinguished by the term Thermo-Electric-Magnetism, the preceding being termed Hyro-Electric-Magnetism, to distinguish the means by which the powers are excited in the two cases.

6. Another discovery still remains to be noticed in this novel and prolific branch of natural philosophy: hitherto it was understood that two different metals were necessary for exciting the electro-magnetic action in the conducting wire, whether the excitation was produced by acids or by caloric; but Professor Moll, of Utrecht, has shown by some recent experiments, that this is not the case, for that one metal with acids will exhibit all the leading phenomena to which we have above referred.

7. The above is a very concise view of the present state of electro-magnetism; we shall now proceed to examine more particularly the discoveries of the different philosophers to whom we have referred, and to

point out more distinctly the nature of the experiments they have made, according to the order of priority of date; but so anxiously and promptly were the experiments of Mr. Oersted repeated, that it is sometimes difficult to decide to whom the original idea of any particular experiment belongs; in many instances, the same discovery seems to have had birth, as it were, at the same instant, in the most remote parts of Europe; and the succession of ideas to have observed the same order and concatenation. In some instances, the dates of the experiments are recorded; but in others, they are not, and we cannot therefore, in every case, answer for the correctness of the following arrangement: it is presumed, however, that it will not be found very erroneous.

§ II. *Detail of electro-magnetic experiments, according to the order in which they have been made by the different authors.*

1. *Experiments of Professor Oersted.*

rofessor ersted's iscovery.

8. The first experiments, in reference to date, as well as in the natural order of developement, were those of the above distinguished philosopher; and which he published in the several journals of the continent, and in England, in nearly the following terms.

The galvanic machine being charged, and its poles connected by a wire of any metal, (which may be called the conductor, or uniting wire,) the following effects on a magnetised needle were produced.

Let the straight part of the wire be placed horizontally above the magnetic needle properly suspended, and parallel to it; the uniting wire, if necessary, being bent so as to assume a proper position for the experiment. Things being in this state, the needle will be moved, and the end of it next the negative side of the battery will go westward, (see fig. 1.) If the distance of the uniting wire does not exceed three quarters of an inch from the needle, the declination of the needle makes an angle of about 45°, and if the distance be increased, the angle diminishes proportionally. The declination likewise varies with the power of the battery.

ig. 1.

The uniting wire may change its place, either towards the east or west, provided it continues parallel to the needle, without any other change of the effect than in respect to its quantity; consequently the effect cannot be ascribed to attraction; for the same pole of the magnetic needle which approaches the uniting wire, while placed on its east side, ought to recede from it when on the west side, if these declinations depended on attraction and repulsion. The uniting conductor may consist of several wires or metallic ribbons connected together, and the nature of the metal does not alter the effect, but merely the quantity. Wires of platinum, gold, silver, brass, iron, ribbons of lead and tin, a mass of mercury, were employed with equal success. The conductor does not lose its effect though interrupted by water, unless the interruption amounts to several inches in length.

The effect of the uniting wire passes to the needle through glass, metals, wood, water, resin, stone ware, stones, for it is not taken away by interposing plates of glass, metal, or wood; even glass, metal, and wood, interposed at once, do not destroy, and indeed scarcely diminish the effect. The disc of the electrophorus, plates of porphyry, a stone-ware vessel, even filled with water, were interposed with the same result. The author found, indeed, the effects unchanged when the needle was included in a brass box filled with water; and this, it should be observed, is the first instance in which electricity was known to transmit its effects through non-conducting substances; and from which we may infer that it is not actually the electric fluid that is transmitted, but some power that is excited by its presence. If the uniting wire be placed in a horizontal plane under the magnetic needle, all the effects are the same as when it is above the needle, only they are in opposite directions; for the pole of the magnetic needle next the negative end of the battery then declines to the east, (fig. 2.)

Fig. 2.

That these facts may be more easily retained, we may use this formula, viz. the pole, above which the negative electricity enters, is turned to the *west*; under which, to the *east*.

If the uniting wire be so turned in a horizontal plane, as to form a gradually increasing angle with the magnetic meridian, the declination of the needle *increases*, if the motion of the wire be towards the place of the disturbed needle; but it diminishes if the wire moves further from that place. When the uniting wire is situated in the same horizontal plane as that in which the needle moves, and parallel to it, no declination is produced either to the east or to the west; but an *inclination* takes place, so that the pole, next which the negative electricity enters the wire, is *depressed*, when the wire is situated on the west side, and elevated when situated on the east side, (fig. 3.) If the uniting wire be placed perpendicular to the plane of the magnetic meridian, whether above or below it, the needle remains at rest, unless it be very near the pole; in that case the pole is *elevated* when the entrance is from the *west* side of the wire, and depressed when from the east side, (fig. 4.)—*Note.* It should be observed, that more recent experiments have shown that, with sufficient power, the needle is inverted in this position of the wire.

Fig. 3.

Fig. 4.

When the uniting wire is placed perpendicularly opposite to the pole of the magnetic needle, and the upper extremity of the wire receives the negative electricity, the pole is moved towards the east; but when the wire is opposite to a point between the pole and the middle of the needle, the pole is moved towards the west; but when the upper end of the wire receives positive electricity, the phenomena are reversed.

If the uniting wire be bent so as to form two legs parallel to each other, it repels or attracts the magnetic poles according to the different conditions of the case. Suppose, for example, the wire placed opposite to either pole of the needle, so that the plane of the parallel legs is perpendicular to the magnetic meridian, and let the eastern leg be united with the negative end, the western leg with the positive end of the battery; in that case, the nearest pole will be *repelled* either to the east or west, according to the position of the plane of the leg; but the eastern leg being united with the positive, and the western with the negative side of the battery, the nearest pole will be *attracted*. When the plane of the legs is placed perpendicularly to the place between the pole and the middle of the needle, the same effects recur, but reversed.

A brass needle, suspended like a magnetic needle, is not moved by the effect of the uniting wire. Needles of glass and of gum lac, remain likewise quiescent.

Such were the first discoveries of this interesting and popular science.

Subsequent experiments by Oersted.

9. Mr. Oersted did not, however, stop here; he pursued the experiments he had so happily begun, and discovered, independent of what was going forward in Paris, that the magnetism excited by electric action, resembled that of the magnet itself, so far as to give direction to the magnetic meridian; or, in other words, that such a combination was, as the needle itself, under the direction and influence of the terrestrial magnetism; a discovery, however, in which he had been anticipated by Ampere.

To Professor Oersted we also owe the important discovery, that electro-magnetic effects do not depend upon the intensity of the electricity, but solely on its quantity. He found that a plate of zinc, six inches square, immersed into a copper vessel containing the dilute acid, produced a considerable magnetic effect; but when the plate had 100 square inches surface, it acted upon the needle with such force, that the effects upon it were visible at the distance of three feet; and when forty such troughs were employed, the effect was found to be rather diminished than increased.

In making these experiments, the difference in the direction of the currents, between a simple combination of two plates, and that of a compound battery, presented itself, and is thus explained by the author:

Fig. 5.

"Let fig. 5, represent a galvanic arc, composed of one piece of zinc *z*, a piece of copper *c*, a metallic wire *a b*, and a fluid conductor *l*. The zinc always communicates a portion of its positive electricity to the water, as the copper does of its negative electricity, which would produce an accumulation of negative electricity in the upper part of the zinc, and of positive electricity in the upper part of the copper, if the communication by *a b* did not reestablish the equilibrium, by presenting a free passage to the negative electricity from *g* to *c*, and of the positive electricity from *c* to *g*; the wire *a b*, therefore, receives the negative electricity of the zinc, and the positive electricity of the copper; whereas a wire which forms a communication between the two poles of a battery, receives positive electricity from the pole of the zinc, and negative from that of the copper.

If we attend to this distinction, says Mr. Oersted, we may, with a single galvanic arc, arranged as I have described, repeat all the experiments which I had before made with a compound galvanic apparatus. One great advantage of this plan is, that we may form the arc sufficiently light to be suspended by a small metallic wire, so as to revolve round the axis of the wire prolonged; and in this way we may examine the action of a magnet on the galvanic arc.

Fig. 6.

For this purpose I employed the arrangement, in fig. 6, which is a perpendicular section of it in the direction of its breadth, *c c c c* being a trough of copper, three inches high, four inches long, and half an inch wide, *z z* a plate of zinc, kept in its place by two pieces of cork *l l*; *c f f f f z*, a brass wire about a quarter of a line in diameter; *a b*, a brass wire as small as possible, but capable of sustaining the apparatus; *c a c*, a linen thread for attaching the wire to the apparatus, or trough which contains the nonconducting fluid. The uniting wire of this apparatus will attract the north pole of the needle when it is placed on the left side of the plane *c f f f f z*, regarded in the direction *f z*. On the same side, the south pole will be repelled; on the other side of this plane, the north pole will be repelled and the south pole attracted. In effecting this, we must not place the needle above *f f*, nor below *f z*, or *f c*. If, instead of presenting a small moveable needle to the uniting wire, we present to one of the extremities *f f*, one of the poles of a strong magnet, the attraction or repulsion (indicated by the needle) will cause the galvanic apparatus to revolve round the prolonged axis of the wire *a b*.

If we substitute, in place of the conducting wire, a large ribbon of copper of the same breadth as the plate of zinc, a feebler effect only is produced. The effect is, on the other hand, increased by making the conductor very short.

Fig. 7. Fig. 8.

Fig. 7, represents the perpendicular section of this arrangement, in the direction of the breadth of the trough; and fig. 8, is a perspective view of it, in which *a b c d e f* represents the conducting plate, and *c z z f* the plate of zinc. Here the north pole of the needle will be attracted towards the plane of *a b c*, and the south pole will be repelled from the same plane; *e d f* will have contrary effects. In this apparatus the extremities act like the poles of the needle, but it is only the faces of the extremities, and not the intermediate parts that have this analogy.

A moveable galvanic apparatus may also be made of two plates, one of copper, and one of zinc, twisted into spirals, and suspended in the conducting fluid. This apparatus is more moveable, but greater precautions are necessary to avoid deception, when experiments are made with it.

At this time Professor Oersted had not been able to exhibit the terrestrial action upon his electro-magnetic arc, but he did afterwards succeed, although not before he had been anticipated in the discovery by Ampere, as above stated.

2. *Experiments by MM. Ampere, Arago, Biot, and other philosophers of France.*

10. We may state generally the following as the discoveries of these three distinguished philosophers. First, M. Arago discovered the magnetic power of the conducting wire upon steel filings, and the possibility of magnetising steel bars by means of the electric current.

Biot's experiments

M. Biot, by some delicate experiments made upon a very long and fine conducting vertical wire, proved, by observing the oscillations of a needle in its vicinity, that the following laws were observable in its action; viz. "From the point were the particle resides, conceive a perpendicular line to be drawn to the axis of the wire. The force which acts on this particle is perpendicular to this line and to the axis of the wire, and *its intensity is in the inverse ratio of the simple distance*. The nature of the action is the same as that of a magnetic needle, which is placed tangentially to the contour of the wire, so that a particle of austral, and a particle of boreal magnetism would be drawn in opposite directions, although always in the same right line determined by the preceding construction."

It will be seen in a subsequent article, where we have given an account of Mr. Barlow's experiments ctro- netism

on the mathematical laws of electro-magnetism, that the general expression for the action of a vertical wire, is

$$\int \frac{dx}{\delta^2 + x^2} = \frac{1}{\delta} \text{ arc tan } \frac{x}{\delta};$$

and which, when $x = l$, becomes

$$\frac{2}{\delta} \text{ arc tan } \frac{l}{\delta};$$

and which last, of course, when l is infinite, or very long, reduces to $\frac{2}{\delta} \times$ arc of 90°.

That is, the force ought to diminish according to the inverse law of the simple distance, although the action between particle and particle varies inversely as the square of the distance.

ere rago's ti- s.

11. The discoveries of M. Ampere were very considerable, both in number and importance: to this philosopher we are indebted for the idea of the spiral wire for magnetising needles, and for exhibiting electro-magnetic effects in a manner so as to resemble those of a common steel bar; he was also the first to show the action of the earth, or of the terrestrial magnetism, upon electro-magnetic combinations; and particularly for the discovery of the mutual action of two galvanic wires on each other, while in connection with the poles of the battery. This discovery he afterwards made the foundation of his theory of electro-magnetism, on which he endeavours to show that magnets themselves owe their properties only to the electric currents which are perpetually circulating in planes perpendicular to their axes. The discoveries of Mr. Faraday, respecting the rotation of the conducting wire and magnet about each other, led him afterwards to modify his hypothesis, and to attribute the effects to currents made about each particle, but still in the same plane, and according to the same manner. From these experiments of M. Ampere, he shows that when two parallel currents of electricity are passing in the same direction, they *attract* each other, and when in opposite directions they *repel*.

In a subsequent part of this treatise we shall exhibit these as a part of the general course of electro-magnetic experiments; and it is therefore unnecessary to enter upon them at length in this place; but still a connected view of what was effected in this science in Paris, within the first few months of its being known, will be both interesting and instructive, and we avail ourselves in giving the following detail from an excellent article published in the *Annals of Philosophy*, which, although anonymous, is evidently from the pen of one who has taken great pains to inform himself of every particular.

12. At a meeting of the Royal Academy on September 18, 1820, M. Ampere described an experiment, proving that the voltaic pile itself acted in the same manner as the wire, connecting its two poles, and produced an instrument which, at the same time that it proved this action, was shown to be of great use in experiments on currents of electricity. This was merely a magnetic needle, but, from the uses to which it was applied, was called a *galvanometer*. When placed near a pile, or trough, in action, having its poles connected either by a wire, or by introducing them into one cell, it immediately moved; becoming obedient to the battery in the same manner as to the connecting wire, and the motions were such as if the battery were simply a continuation, or part, of the wire. In consequence of this action, the needle becomes an instrument competent to indicate that state of an active voltaic pile, and the wire connecting it, which is supposed to be occasioned by currents of electricity, and in which only, magnetism has yet been discovered.

Progress of Discovery.

Ampere's experiments continued.

On Sept. 25, M. Ampere announced the new fact of the attraction and repulsion of two wires connecting the poles of a battery; and showed that the magnetic needle, which had previously been used to prove the magnetic attractions and repulsions of the wire, could be replaced by another connecting wire like the first. This discovery seemed to free the phenomena of magnetism from any peculiar power resident in the magnet, and to prove its production by electricity alone. When by Oersted's discovery it had been shown that a wire connecting the poles of a voltaic battery would act on a magnet, attracting and repelling it, just as another magnet would do, it was fair to assume that the wire possessed the powers of the magnet it supplied; and when the second magnet was replaced by another connecting wire, as in Ampere's experiment, and the powers and actions still remained as before, it was perfectly correct to consider these powers and actions as magnetical; so that it became evident that magnetism could be exerted independently of magnets, as they are usually called, and of any of the means of excitation usually employed, but wholly by electricity, and in any good electrically conducting medium. The phenomena with two conductors situated between the poles of the battery are as follows: When they are parallel to each other, and the same ends of them are similarly related to the battery; i. e. when the supposed currents, existing in them, are in the same direction, then they attract each other; but if the opposite ends be connected with the battery, so that the currents conceived to exist in them are in opposite directions, they repel each other. If, also, the one being fixed, the other moveable, and the currents be sent, or the connections be made in opposite directions, then the moveable one will turn round until they are in the same direction. The contrast between these attractions and repulsions, and those usually called electrical, are very striking. These take place only when the circuit is complete; those only when it is incomplete. The attractions take place between the similar ends of the wires, and repulsions between the dissimilar ends; but the electrical attractions take place between dissimilar ends, and the repulsion between similar ends. These take place in vacuo, but those do not. When the magnetic attraction brings the two wires together, they remain in contact; but when electrical attraction brings two bodies together, they separate after the contact.

These experiments are varied in several ways by M. Ampere; and the apparatus with which they were made, appears, from the plates and descriptions published, to be very delicate, ingenious, and effectual. The general results drawn up by M. Ampere himself from them are; 1st, that two electrical currents attract when they move parallel to each other, and in the same direction; and repel when they move parallel to each other in a contrary direction; 2ndly, that when the metallic wires traversed by these currents can only turn in parallel planes, each of the currents tend to direct the other into a situation in which it shall be parallel, and in the same direction; and, 3dly, that these attractions and repulsions are entirely different from the ordinary electrical attractions and repulsions.

M. Arago's experiments.

13. On Sept. 25, M. Arago stated to the Royal Academy of Sciences, that he had ascertained the attraction of iron filings by the connecting wire of the battery, exactly as by a magnet. This fact proved not only that the wire had the power of acting on bodies already magnetised, but that it was itself capable of developing magnetism in iron, that did not previously possess this power. When the wire in connection with the poles of the battery was dipped into a heap of filings, it became covered with it, increasing its diameter to the size of a goose quill; the instant the communication was broken at either pole, the filings dropped off; and the instant it was re-established, they were reattracted. This attraction took place with wires of brass, silver, platina, &c. and was so strong as to act on the filings when the wire was brought near them without actual contact. It was shown not to belong to any permanent magnetism in the wire or filings, by the inactivity of both when the connection was not made with the battery; and it was proved not to be electrical attraction, by the connecting wire having no power over filings of copper, or brass, or over sawdust. When soft iron was used, the magnetism given was only momentary; but on repeating the experiment with some modification, M. Arago succeeded completely in magnetising a sewing needle permanently.

M. Ampere's theory.

14. The theory which M. Ampere had formed to account for the magnetic phenomena of magnets by electrical powers only, assumed that magnets were only masses of matter, around the axis of which electrical currents were moving in closed curves. This theory led him, when informed by M. Arago of his experiments, to expect a much greater effect if the connecting wire were put into the form of a spiral, and the piece to be magnetised were placed in its axis. According to the theory, in a needle or magnet, pointing to the north, the currents were in the upper part from east to west. In consequence of these exceptions, MM. Ampere and Arago made experiments with spirals, or helices, and the results are mentioned in M. Arago's paper, on the Communication of Magnetism to Iron Filings, published in the *Annales de Chimie*, xv. 93; so that probably the experiments date from Sept. 25, though there is no date to the paper.

On twisting a wire round a rod, it may be made to pass either in one direction or the other, giving rise to two distinct but symmetrical helices, which have been named by botanists *dextrorsum* and *sinistrorsum*. The dextrorsum, or, as we may call it, the right helix, proceeds from the right hand downwards towards the left above the axis; the tendrils of many plants exhibit instances of it, and it is almost exclusively used in the arts; the sinistrorsum, or left helix, proceeds from the left hand downwards towards the right above the axis.

Having made some of these helices, one was connected by its extremities with the poles of a voltaic battery, and then a needle wrapped in paper placed within it; after remaining there a few minutes, it was taken out, and found to be strongly magnetised; and the effect of a helix above that of a straight connecting wire was found to be very great.

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Then with regard to the position of the poles in the magnetised needle, it was found that whenever a right helix was used, that end of the needle towards the negative end of the battery pointed to the north, and that towards the positive end towards the south; but that with a left helix, that end of the needle towards the positive, pointed north; and the other end south.

In order to establish this point, the connecting wire was sometimes formed into one helix, sometimes into two or three, which was readily done by twisting it round a glass tube, or rod, first in one direction, then another; and when needles (previously enclosed in glass tubes) were placed in these helices, the magnetic poles they received were always in accordance with the statement just given. In one case, also, where the connecting wire had been formed into three consecutive helices, the middle one being of course different to the other two, a single piece of steel wire sufficiently long to pass through all three of them being enclosed in a glass tube, was placed within them. On being again removed, and examined, it was found to have six poles; first, a north pole, a little further on a south pole, then another south pole, a north pole, another north pole, and at the further end a south pole.

In the same paper, M. Arago also states, that when the connecting wire was perfectly straight, a needle placed beneath and parallel to it was not at all magnetised. He also states, that it sometimes happened, though not frequently, that the copper wire connecting the poles of the battery retained its magnetism for a few instants after the connection had been broken; and also that M. Boisgeraud had observed the same fact with a platina wire. These wires, it is said, would sometimes take up iron filings, or even a needle, when separated from the battery; but the power soon disappeared, and could not be reproduced at pleasure.

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15. On Oct. 9, M. Boisgeraud read a paper to the Royal Academy of Sciences, containing the detail of numerous experiments, most of which, however, are variations of Oersted's first experiments. He remarked that connecting wires, or arcs, placed any where in the battery, would effect the needle—a result that follows as a consequence from Oersted and Ampere's experiments. He notices the difference of intensity in the effects produced when electrical conductors were employed to complete the circuit—a difference which Oersted himself had pointed out in the case of water. M. Boisgeraud, however, proposes to ascertain the conducting power of different substances by placing them in one of the arcs, cells, or divisions, of the battery, and bringing the magnetic needle, or Ampere's galvanometer, towards another arc, viz. to the wire, or other connecting body used to complete the circuit in the battery. With regard to the positions, which M. Boisgeraud notices of the needle and wire, they are all confirmatory of Oersted's statement.

16. On Oct. 9, M. Ampere read another Memoir on the phenomena of the voltaic pile, and on the method he intended to pursue in calculating, the action of two rectilineal electrical currents. At this sitting also, he showed the mutual action of two

rectilineal electrical currents; i. e. of two straight portions of the connecting wires; for it appears that the phenomena of attraction, repulsion, &c. were first observed with spiral wires. These actions, however, are exactly similar; and the view already given of them, as it relates to straight wires, is consequently more simple than the description of the effects with spiral wires can be; i. e. considering it as a matter of experiment only, and not of theory.

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In consequence of the view which M. Ampere had taken of the nature of magnetism as dependant simply upon currents of electricity, it became an important object with him to ascertain the action of the earth upon such currents, excited by the voltaic battery; for, from this theory, he expected that it would be equally efficient in directing these currents as in directing those supposed to exist in the magnetic needle. After some trials, he succeeded in overcoming the obstacles he found, in forming sufficiently delicate suspension, contact, &c. and constructed an apparatus, in which a part of the wire, connecting the two poles of a battery, was rendered so light, and mobile, as to move immediately the connection was completed with the pole, and took a direction which, with regard to the earth, was almost constant, and in accordance with M. Ampere's theory. An account of these experiments, with the apparatus used in them, was read to the Royal Academy on Oct. 30. The first consisted of a wire bent so as to form almost a complete circle, of about sixteen inches in diameter; the two extremities were made to approach, and were placed one just beneath the other; and being attached to two steel points, were connected by them with two little basins of platina containing mercury, fixed so as to receive them: one of the points only touched the bottom of the cup it was placed in; so that the friction was scarcely sensible, and the mercury secured a good contact. The cups were connected with other wires that passed off to the voltaic battery; so that it was easy to make this moveable circle connect either one way or the other between the poles; and being enclosed in a glass case, any movement it might receive was readily observable, without danger of its resulting from any other cause than the electric action.

When the extremities of this apparatus were connected with the poles of a battery, the circle immediately moved, and, after some oscillations, placed itself in a plane perpendicular to the magnetic meridian of the earth; and on every repetition of the experiment, the same effect took place. The direction in which it moved depended upon the way in which the connection had been made with the battery; and if it be assumed that there is a current passing through the wire from the positive to the negative end, the curve so arranged itself, that that current always passed downwards on the eastern side, and upwards on the western. This circle moved round a perpendicular, and, therefore, only represented the direction of the magnetic needle; in order to represent the dip, a wire was formed into a parallelogram, and being fixed to a glass axis, was suspended by fine points, and connected as before, so as to move round a horizontal axis; then this axis being placed perpendicular to the magnetic meridian, and the wires being connected with the poles of a battery, the parallelogram immediately moved towards a position in the plane perpendicular to the dipping needle; when the communication was broken, it returned towards its first position; and when renewed, it resumed the second, evidently indicating the magnetic influence of the earth over it. In consequence of the difficulty of placing the centre of gravity in the centre of suspension, and keeping it there, this conductor did not take its position exactly in a plane perpendicular to the dipping needle, but approached towards it, till in equilibrium between the magnetic and the gravitating powers of the earth. These instruments are more particularly described in our general course of experiments.

On Oct. 30, MM. Biot and Savart read a Memoir to the Academy of Sciences, the object of which was to determine the law by which a connecting wire acted on magnetised bodies; the general object of which has been already stated at the beginning of this section.

Arago magnetises needles with the electrical machine.

17. Having succeeded in magnetising iron and steel by the wire discharging the voltaic apparatus, M. Arago was led to expect the same effect from common electricity; and on trial found the results to be the same. He announces this fact verbally to the Royal Academy, on Nov. 6, stating that he had produced all the phenomena in this way, which he had observed in using voltaic electricity.

18. In consequence of M. Ampere's theory, which attributed the powers of magnets to electrical currents, and also of the views taken of the manner in which it was supposed the currents of electricity in the connecting wire, induced currents in the steel bars placed near them, as in M. Arago's experiments, it was earnestly hoped and expected that such an arrangement might be made of magnets, wires, &c. as to produce the decomposition of water, or some other electrical effects; for, as electricity produced magnetism, it was considered that magnetism might produce electricity. Many arrangements were made of magnets together, and of wires about and round magnets; and at first it was stated that electrical effects, such as the decomposition of water, attractions, &c. had been produced; but on Nov. 6, M. Fresnel, who had been very earnest in his endeavours to obtain these effects, admitted to the Royal Academy, that the appearances were not such as to authorize the conclusion, that any certain effect had been obtained.

Magnet imitated by a spiral wire.

19. At the same sitting, also (Nov. 6) M. Ampere noticed an effect produced by the connecting wire formed into a helix. This may be easily understood by considering that the direction of the magnetic power is always perpendicular to the conducting wire. When, therefore, the conducting wire is parallel to the axis of the helix, the power is perpendicular to that axis; when the wire forms a circle round the axis, in a plane perpendicular to it, the power is in the direction of the axis; but when, as in the helix, it passes round the axis in a direction intermediate between parallelism and perpendicularity, the direction of the power is of course inclined accordingly. In this case the power may be considered as composed of two portions; one perpendicular to the axis, the other parallel to it. As M. Ampere considered magnets to be assemblages of currents perpendicular to their axis, he wished, in his imitation

of them, to do away with that effect due to the extension of the wire in the direction of the axis of the helix, and succeeded in this attempt by making the wire at one end return through the helix, so as not to touch it in any part; for in this position, its magnetic effects being contrary to those belonging to the length of the helix, and also near to them, they neutralise, or hide each other. An imitation of a magnet was now made by forming a helix, and making the wire at the two extremities return through the centre of the helix half-way, and then pass out upwards and downwards, so as to form a perpendicular axis on which the whole might move. The extremities of a battery being connected with these two ends of the wire, the helix became magnetical, and was attracted and repelled by a magnet, precisely as a real magnet would have been.

Miscellaneous experiments.

20. On Nov. 13, M. Lehot stated to the Academy of Sciences, that, notwithstanding the results obtained by M. Fresnel, he was still convinced of the decomposing power given to iron wires by magnets; and quotes experiments he had made six years before, by connecting iron wires to the poles of a magnet, and then immersing their ends in water. The south pole caused oxidation, the north pole preserved its wire bright; again in tincture of litmus, the south pole reddened the tincture, the north pole did not. There does not, however, seem any reason to consider these experiments as decisive; and M. Lehot himself does not attach more importance to them than to those made twenty years ago by Ritter, and on the uncertainty of which M. Fresnel had sufficiently remarked.

On Nov. 13, also, M. Ampere read a note on the electro-chemical effects of a spiral wire, subjected to the action of the earth alone. The wire formed a helix round a paper cylinder, the axis of which was placed parallel to the dip and direction of the needle, the extremities were placed in a solution of common salt. In seven days gas appeared on both ends, but most on that answering to the negative end of the battery; the bubbles were displaced, but fresh ones appeared, the end remaining bright, while the other end became oxidized, and gave no more gas. On the whole, however, the experiments seemed uncertain, especially after what M. Fresnel had said; and M. Ampere himself stated, that he still doubted as to the existence of the action.

3. *Experiments by Sir H. Davy.—First series.*

Sir H. Davy's experiments. First series.

21. Sir Humphry Davy was amongst the first philosophers who repeated Mr. Oersted's experiments, and was thus led to the discovery of several curious facts, some of which, however, were, during the same time, fallen upon by others. These results were communicated to the Royal Society, through a letter addressed to Dr. Wollaston, dated November 16, 1820; but the experiments detailed in it were principally made in the preceding month. The following is very little more than a bare enumeration of the facts which it contains, namely:

That the wire in connection affected the needle as Mr. Oersted described; the effect was immediately attributed to the wire itself becoming a magnet; and this was instantly proved by bringing it near iron filings, which were attracted, and remained attached to it as long as the communication continued. This is, in fact, the same experiment as that made by M. Arago, but it was made by the two philosophers, independent of each other; and as no detail of M. Arago's experiments has, as yet, been published, the accurate description of Sir H. Davy's will be found highly interesting. This effect took place in any part of the wire, and any where in the battery. Steel needles placed on the connecting wire became magnetic; those parallel to the wire acted like the wire itself; those across it had, each, two poles; such as were placed under the wire, the positive end of the battery being east, had north poles on the south of the wire, and south poles to the north; those needles above were in the opposite direction; and this was constantly the case, whatever the inclination of the needle to the wire might be. This position, it will be observed, is precisely that which has been referred to in the account of Mr. Oersted's experiments. On breaking the connection, the steel needles across retained their magnetism, while those parallel to the wire lost it at the moment. Wires of platina, silver, &c. in the same situation, were not rendered magnetic, except when, by accident, they formed part of the circuit. Whatever the position of the battery, or wire, the effect was the same. Contact was found not necessary; instantaneous effect was produced by mere juxtaposition, though thick glass intervened; filings arranged themselves in right lines across the wire on a glass plate, held over it at a quarter of an inch distance. The effect was proportional to the quantity of electricity passing through a given space, without any relation to the metal transmitting it. Increasing the size of the plates, proportionally increased the magnetic effects of the connecting wires. The wire connecting a battery of sixty pair of plates, did not take up half so many filings as when the battery was arranged so as to form thirty pair of plates twice the size. The magnetic power of the wires rose with its heat.

Considering that a great quantity of electricity was necessary to produce sensible magnetism, Sir H. Davy concluded, that a current from the common machine would have no effect, whilst a discharge would; and this was found to be true; the poles of the needle magnetised, being situated exactly as before. In these experiments a battery of seventeen square feet, highly charged, being discharged through a silver wire, one-twentieth of an inch in diameter, rendered bars of steel of two inches long, from one-tenth to one-twentieth thick, so magnetic, as to lift up pieces of steel wire, and needles; and the effect was communicated to needles, at a distance of five inches from the wire, even when water, or thick plates of glass, or metal intervened.

By these kinds of experiments it was found, that a tube of sulphuric acid, one-fourth of an inch in diameter, did not conduct electricity enough to render steel magnetic; that an explosion through air, made the needle, placed transversely to it, magnetic; though not so strongly as a wire would have done; that steel bars in the circuit, or parallel to it, did not become magnets; that two bars placed together across the wire, passing through the common centre of gravity, showed no magnetism after the discharge, before they were separated, but exhibited poles on separation.

One conclusion drawn by the author from these experiments is, that magnetism is produced whenever concentrated electricity is passed through space.

Electro-magnetism

On arranging numerous wires in circles, and in other directions around and about the discharging wire, it was found after the discharge, that all were magnetic, and the poles exactly as before expressed; so that the north pole of one needle was towards the south pole of the next, and in a constant relation to the course of the discharge.

The connecting wire being divided in one part into three, four, or more, by small wires, and a voltaic battery discharged through them, they were all found magnetic at once, and took up different cylinders of filings; when the opposite side of two of these were brought together, the filings attracted each other. From this, it was expected, that when the similar sides were brought together, the filings on them would repel each other. This was tried by two batteries arranged parallel, but in opposite directions. The filings on these connecting wires repelled each other; and connecting wires of platinum, and fine steel wire without filings, exhibited similar phenomena of attraction and repulsion. These experiments, it will be perceived, are similar to those made by M. Ampere, on the attraction and repulsion of two connecting wires, or, as he calls them, two electrical currents, and prove the same thing. On placing straight pieces of platinum, silver, and copper wire, on two knife-edges of platinum connected with the opposite poles of a battery, they were found to be attracted and repelled in directions according to what has been said. Gold leaf made in the same way to form the connection, was found to be moved by a magnet.

4. *Experiments by Sir H. Davy.—Second series.*

Sir H. Davy's second series of experiments.

22. At the conclusion of the paper, of which the above is an abridgement, Sir H. Davy mentions some other experiments he had in view, and which he afterwards performed and made the subject of another memoir. It would be useless to attempt any condensation of these results into less space than they occupy; we believe, therefore, that we can only do justice to the author, by giving the particulars as they are stated in the article itself, which is as follows:

"In my letter to Dr. Wollaston, on the new facts discovered by Mr. Oersted, which the Society has done me the honour to publish, I mentioned that I was not able to render a bar of steel magnetic, by transmitting the electrical discharge across it, through a tube filled with sulphuric acid; and I likewise mentioned, that the electrical discharge passed across a piece of steel through air, rendered it less magnetic than when passed through a metallic wire; and I attribute the first circumstance to the sulphuric acid being too bad a conductor to transmit a sufficient quantity of electricity for the effect; and the second, to the electricity passing through air in a more diffused state than through metals.

"To gain some distinct knowledge on the relation of the different conductors to the magnetism produced by electricity, I instituted a series of experiments, which led to very decisive results, and confirmed my first views.

On the effect of conductors.

23. "I found that the magnetic phenomena were precisely the same, whether the electricity was small in quantity, and passing through good conductors of considerable magnitude; or, whether the conductors were so imperfect as to convey only a small quantity of electricity; and in both cases they were neither attractive of each other, nor of iron filings, and not affected by the magnet; and the only proof of their being magnetic, was their occasioning a certain small deviation of the magnetised needle.

Progress of Discovery.

"Thus a large piece of charcoal placed in the circuit of a very powerful battery, being a very bad conductor compared with the metals, would not affect the compass needle at all, unless it had a very large contact with the metallic part of the circuit; and if a small wire was made to touch it in the circuit, only in a few points, that wire did not gain the power of attracting iron filings; though when it was made to touch a surface of platinum foil coiled round the end of the charcoal, a slight effect of this kind was produced. And in a similar manner fused hydrate of potassa, one of the best of the imperfect conductors, could never be made to exert any attractive force on iron filings, nor could the smallest filaments of cotton moistened by solution of hydrate of potassa placed in the circuit, be made to move by the magnet; nor did steel needles, floating on cork on an electrised solution of this kind, placed in the voltaic circuit, gain any polarity; and the only proof of the magnetic powers of electricity passing through such a fluid, was afforded by its effect upon the magnetised needle, when the metallic surfaces, plunged in the fluid, were of considerable extent; that the mobility of the parts of fluids did not interfere with their magnetic powers, as developed by electricity, was proved by electrifying mercury and Newton's metal fused in small tubes. These tubes, placed in a proper voltaic circuit, attracted iron filings, and gave magnetic powers to needles; nor did any agitation of the mercury or metal within, either in consequence of mechanical motion or heat, alter or suspend their polarity.

Imperfect conducting fluids.

24. "Imperfect conducting fluids do not give polarity to steel when electricity is passed through them; but electricity passed through air produces this effect. Reasoning on this phenomenon, and on the extreme mobility of the particles of air, I concluded, as M. Arago had likewise done from other considerations, that the voltaic current in air would be affected by the magnet. I failed in my first trial, which I have referred to in a note to my former paper, and in other trials made since, by using too weak a magnet; but I have lately had complete success, and the experiment exhibits a very striking phenomenon.

Experiment on an electrical arc of light.

"Mr. Pepys having had the goodness to charge the great battery of the London Institution, consisting of 2000 double plates of zinc and copper, with a mixture of 1168 parts of water, 108 parts of nitrous acid, and twenty-five parts of sulphuric acid; the poles were connected by charcoal, so as to make an arc, or column of electrical light, varying in length from one to four inches, according to the state of rarefaction of the atmosphere in which it was produced; and a powerful magnet being presented to this arc or column, having its pole at a very acute angle to it, the arc or column was attracted or repelled with a rotatory motion, or made to revolve, by placing the pole in different positions, according to the same law as the electrified cylinder of platinum described in my last paper, being repelled when the negative pole was on the right hand by the north pole of the magnet, and attracted by the south pole, and *vice versâ*.

"It was proved by several experiments, that the motion depended entirely upon the magnetism, and not upon the electrical inductive power of the magnet, for masses of soft iron, or of other metals, produced no effect.

" The electrical arc or column of flame was more easily affected by the magnet, and its motion was more rapid when it passed through dense than through rarefied air; and in this case, the conducting medium, or chain of aeriform particles, was much shorter. I tried to gain similar results with currents of common electricity sent through flame, and in vacuo; they were always affected by the magnet; but it was not possible to obtain so decided a result as with voltaic electricity, because the magnet itself became electrical by induction, and that whether it was insulated, or connected with the ground.

25. " Metals, it is well known, readily transmit large quantities of electricity; and the obvious limit to the quantity which they are capable of transmitting, seems to be their fusibility or volatization, by the heat which electricity produces in its passage through bodies.

" Now I had found in several experiments, that the intensity of this heat was connected with the nature of the medium by which the body was surrounded; thus a wire of platinum, which was readily fused by transmitting the charge from a voltaic battery in the exhausted receiver of an air-pump, acquired in air a much lower degree of temperature.

" Reasoning on this circumstance, it occurred to me, that, by placing wires in a medium much denser than air, such as ether, alcohol, oils, or water, I might enable them to transmit a much higher charge of electricity than they could convey without being destroyed in air; and thus not only gain some new results as to the magnetic states of such wire, but likewise perhaps determine the actual limits to the powers of different bodies to conduct electricity, and the relations of these powers.

" A wire of platinum of $\frac{1}{70}$ diameter and three inches in length, was fused in air, by being made to transmit the electricity of two batteries of ten zinc plates of four inches, with double copper, strongly charged: a similar wire was placed in sulphuric ether, and the charge transmitted through it. It became surrounded by globules of gas, but no other change took place; and in this situation it bore the discharge from twelve batteries of the same kind, exhibiting the same phenomena. When only about an inch of it was heated by this high power in ether, it made the ether boil, and became white hot under the globules of vapour, and then rapidly decomposed the ether, but it did not fuse. When oil or water was substituted for the ether, the length of the wire remaining the same, it was partially covered with small globules of gas, but did not become red-hot.

" On trying the magnetic powers of this wire in water, they were found to be very great, and the quantity of iron filings that it attracted, was such as to form a cylinder round it, of nearly the tenth of an inch in diameter. To ascertain whether short lengths of fine wire, prevented from fusing by being kept cool, transmitted the whole electricity of powerful voltaic batteries, I made a second independent circuit from the ends of the battery with silver wires in water; so that the chemical decomposition of the water indicated a residuum of electricity in the battery, operating in this way, I found that an inch of wire of platinum of $\frac{1}{70}$ diameter, kept cool by water, left a great residual charge of electricity in a combination of twelve batteries, of the same kind as those above mentioned, and after making several trials, I found that it was barely adequate to discharge six batteries.

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26. " Having determined that there was a *limit* to the quantity of electricity which wires were capable of transmitting, it became easy to institute experiments on the different conducting powers of different metallic substances, and on the relation of this power to the temperature, mass, surface, or length, of the conducting body, and to the conditions of electro-magnetic action.

" These experiments were made as nearly as possible under the same circumstances, the same connecting copper wire being used in all cases, their diameter being more than one-tenth of an inch, and the contact being always preserved perfect, and parts of the same solution of acid and water were employed in the different batteries, and the same silver wire and broken circuit with water were employed in different trials; and when no globules of gas were observed upon the negative silver wire of the second circuit, it was concluded that the metallic conducting chain, or the primary circuit, was adequate to the discharge of the combination. To describe more minutely all the precaution observed, would be tedious to those persons who are accustomed to experiments with the voltaic apparatus, and unintelligible to others; and, after all, in researches of this nature, it is impossible to gain more than approximations to true results; for the gas disengaged upon the plates, the different distances of the connecting plates, and the slight difference of time in making the connections, all interfere with their perfect accuracy.

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" The most remarkable general result that I obtained by these researches, and which I shall mention first, as it influences all the others was, *that the conducting power of metallic bodies varied with the temperature, and was lower in some inverse ratio as the temperature was higher.*

" Thus a wire of platinum of $\frac{1}{70}$, and three inches in length, when kept cool by oil, discharged the electricity of two batteries, or of double plates; but when suffered to be heated by exposure in the air, it barely discharged one battery.

" Whether the heat was occasioned by electricity, or applied to it by some other source, the effect was the same. Thus a wire of platinum, of such length and diameter as to discharge a combination without being considerably heated, when the flame of a spirit lamp was applied to it so as to make a part of it red-hot, lost its power of discharging the whole electricity of the battery, as was shown by the disengagement of abundance of gas in the secondary circuit; which disengagement ceased as soon as the source of heat was withdrawn.

" There are several modes of exhibiting this fact, so as to produce effects, which, till they are witnessed, must almost appear impossible. Thus, let a fine wire of platinum, of four or five inches in length, be placed in a voltaic circuit, so that the electricity passing through it, may heat the whole of it to redness; and let the flame of a spirit lamp be applied to any part of it, so as to heat that part to whiteness, the rest of the wire will instantly become cooled below

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the point of visible ignition. For the converse of the experiment, let a piece of ice, or a stream of cold air, be applied to a part of the wire, the other part will immediately become much hotter, and from a red, will rise to a white heat. The quantity of electricity that can pass through that part of the wire submitted to the changes of temperature, is so much smaller when it is hot than when it is cold, that the absolute temperature of the whole wire is diminished by heating a part of it.

"In comparing the conducting powers of different metals, I found much greater differences than I had expected. Thus, six inches of silver wire of $\frac{1}{220}$, discharged the whole of the electricity of sixty-five pair of plates of zinc and double copper, made active by a mixture of about one part of nitric acid of commerce, and fifteen parts of water. Six inches of copper wire of the same diameter, discharged the electricity of fifty-six pair of the same combination; six inches of tin of the same diameter, carried off that of twelve only; the same quantity of wire of platinum, that of eleven; and of iron, that of nine. Six inches of wire of lead of $\frac{1}{220}$, seemed equal in their conducting powers to the same length of copper wire of $\frac{1}{330}$. All the wires were kept as cool as possible, by immersion in a basin of water. I made a number of experiments of the same kind, but the results were never precisely alike, though they sometimes approached very near each other. When the batteries were highly charged, so that the intensity of the electricity was higher, the differences were less between the best and worst conductors, and they were greater when the charge was extremely feeble. Thus, with a fresh charge of about one part of nitric acid, and nine parts of water, wires of $\frac{1}{220}$ of silver, and platinum five inches long, discharged, respectively, the electricity of thirty-seven double plates.

"Finding, that when different portions of the same wire plunged in a non-conducting fluid were connected with different parts of the same battery equally charged, their conducting powers appeared in the inverse ratio of their lengths: so when six inches of wire of platinum of $\frac{1}{220}$ discharged the electricity of ten double plates, three inches discharged that of twenty, one inch and a half that of forty, and one inch that of sixty; it occurred to me, that the conducting powers of the different metals might be more easily compared in this way, as it would be possible to make the contacts in less time than when the batteries were changed, and, consequently, with less variation in the charge.

"Operating in this way, I ascertained, that in discharging the electricity of sixty pair of plates, one inch of platinum was equal to about six inches of silver, to five inches and a half of copper, to four of gold, to 3·8 of lead, to about $\frac{9}{10}$ of palladium, and $\frac{8}{10}$ of iron, all the metals being in a cooling fluid medium.

"I found, as might have been expected, that the conducting power of a wire for electricity, in batteries of the size, and numbers of plates just described, was nearly directly as the mass; thus, when a certain length of wire of platinum discharged one battery, the same length of wire, of six times the weight, discharged six batteries; and the effect was exactly the same, provided the wires were kept cool, whether the mass was a single wire, or composed of six of the smaller wires in contact with each other. This result alone showed, that surface had no relation to the conducting power, at least, for electricity of this kind, and it was more distinctly proved by a direct experiment; equal lengths and equal weights of wire of platinum, one round, and one flattened by being passed transversely through rollers, so as to have six or seven times the surface, were compared; as to conducting powers, the flattened wire was the best conductor in air, from its greater cooling powers, but in water no difference could be perceived between them."

Progress of Discovery.

27. These experiments, relative to the conducting power of wires, under different circumstances, are highly important, not only in reference to the construction of electro-magnetic apparatus, as will be seen as we proceed, but they are also calculated to throw great light upon the first principles of electricity and galvanism; and they are followed in the same paper by several others, on the conducting power of fluid menstrua, but these not being immediately applicable to the subject at present under investigation, we shall pass over, and only give further, the concluding section of this valuable memoir, which is stated by the author as follows:

28. "The magnetism produced by electricity, though with the same conductors it increases with the heat, as I mentioned in my last paper; yet with different conductors, I find it follows a very different law. Thus, when a chain is made of different conducting wires, and they are placed in the same circuit, all exhibit equal magnetic powers, and take up equal quantities of iron filings, so that the magnetism seems directly as the quantity of electricity which they transmit. And when in a highly powerful voltaic battery, wires of the same diameters and lengths, but of which the best conducting is incapable of wholly discharging the battery, are made separately and successively to form the circuit, they take up different quantities of iron filings, in some direct proportion to their conducting powers.

"Thus, in one experiment, two inches of wire, of $\frac{1}{30}$ of an inch being used, silver took up thirty-two grains, copper twenty-four, platinum eleven, and iron eight and one-fifth."

5. *Experiments by Mr. Faraday.*

Experiments by Mr. Faraday.

29. At the time, when Mr. Faraday commenced his experiments on this interesting science, in the summer of 1821, nothing had been discovered relative to the magnetic action of the conducting wire, but its directive quality, its power of communicating magnetism, and the action of electrical conductors on each other, as depending on their magnetic, and not on their electrical state. These facts, it is true, are very important, and within the short space that such a power had been known to exist, were highly honourable to the zeal and talents of the philosophers by whom the subject had been pursued. But the experiments we are now about to detail, form an entirely new and distinct feature in the science, and deserve particular notice. Mr. Faraday's object, when he commenced these experiments, was the repetition of those of Mr. Oersted; and having the advantages of a powerful apparatus, he was enabled to mark the various changes that took place in the direction of the needle, under different positions of the conducting wire, with great accuracy and precision; and he therefore soon observed, that the position of the needle, with respect to the wire, greatly modified the effects produced. He

ascertained, for example, that the apparent attraction of the needle on the one pole, and its consequent repulsion on the other, did not occur under all circumstances; but that accordingly as the wire was placed nearer to, or removed farther from, the pivot of the needle, attraction or repulsion was produced on the same side of the wire; that is, says the author, "If the wire be made to approach perpendicularly towards one pole of the needle, that pole will pass off, on one side, in that direction which the attraction and repulsion at the extreme point of the pole would give; but if the wire be continually made to approach the centre of motion, by either the one or the other side of the needle, the tendency to move in the former direction diminishes; it then becomes null, and the needle is quite indifferent to the wire; and, ultimately, the motion is reversed, and the needle powerfully endeavours to pass the opposite way."

From these facts Mr. Faraday conceived the happy idea, that, but for the impossibility of such motion, with the magnet suspended in the usual way, the pole of it would revolve about the wire, and conversely, the wire about the magnet; at least, that they would each have such tendency, if sufficient mobility could be given to them, but still preserving sufficient contact for the transmission of the fluid. Moreover, as the same effects, but in opposite directions, took place with the opposite poles, the author concluded, that each pole had its peculiar power of action on the wire, and not as any part of the needle, or as connected with the opposite pole. The attractions and repulsions hitherto noticed, he considered merely as exhibitions of the tendency to revolution in different parts of the circle.

We shall not attempt to follow Mr. Faraday in this place, through all the various difficulties he had to contend with, in carrying this very ingenious and original idea into execution. It will be sufficient here to state that he succeeded, and was thus the first philosopher that ever produced a rotatory motion, independent of mechanical principles, that is, from a natural force, of which, till this time, no one ever imagined the existence. In our chapter, in which is given a course of electro-magnetic experiments, according to their natural order of dependence on each other, and not on that of the date of their discovery, we shall give Mr. Faraday's experiments in their complete form, but at present we shall content ourselves with describing one of his most simple apparatus, merely for the purpose of illustrating what is stated above.

Fig. 9.

30. This machine is represented in fig. 9; its construction and action being as follow: place a portion of mercury in a tube closed below with a cork, and fix a small magnet so that one pole shall project above the surface of the mercury; take a piece of clean copper wire about two inches in length, amalgamate the two ends, form a loop at one end, and at the end of another piece of wire form another loop, by which hang the first piece, thus affording free motion, and at the same time sufficient contact: fix this over the magnet, so that the end of the moveable piece shall just dip into the mercury; then connect the mercury with one pole of a voltaic combination, which is readily done through the magnet, and the wire with the other, and the moveable part will immediately revolve round the magnetic pole, and continue to do so as long as the contact remains. On bringing the magnetic pole from the centre of motion to the side of the wire, there is neither attraction nor repulsion, but the wire has a tendency to pass off in a circle, still leaving the pole for its centre, and that either on the one side, or on the other, according to circumstances. If the magnet be taken out and reversed, we have still the same kind of motion, but it takes place in an opposite direction; that is, if it were to the right in the first instance, it will now be to the left, the contact with the poles of the battery remaining the same. And if these be reversed, so also will be the motion. Mr. Faraday recommends, that instead of a magnet, as above described, a piece of iron be applied, and a strong magnet used exteriorly, to induce either pole in the iron.

In some future trials a different apparatus was constructed, which exhibited this rotation upon a larger and better scale, and also the rotation round the wire, the latter being fixed, and the former free; but as these will be described in the following general course, this notice of the results will be sufficient for the present.

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31. We have already mentioned the experiments of M. Ampere, by which the effect of the terrestrial magnetism was shown, by giving direction to a galvanic wire; Mr. Faraday was therefore induced to try whether this also was not sufficient to give a rotation to a freely suspended wire of the same kind: at the time when he published his first experiments his attempts had not been successful, but he ultimately obtained the motion and rotation sought. Having assumed the line of the dip as the direction or resultant of all the magnetic forces in any given place, and judging from other experiments, the results expected were, that a connecting wire would always move laterally, and in a plane at right angles to the dip; this required the wire to be perpendicular to the dip; but still if removed from the perpendicular a little way, it was expected that it would still move, although with a diminished force. To obtain this result experimentally, a horizontal piece of wire was suspended from the ceiling by a silk thread; its ends dipped into mercury in two basins, and these were connected with the poles of the battery; the wire immediately moved laterally, and that in every azimuth, the direction of motion being such, that when the wire was east and west, the east end to the zinc, and the west to the copper plate, (a single pair being used,) the motion was towards the north; when the connections were reversed the motion was towards the south. When the wire hung north and south, the north end to the zinc and the south to the copper, the motion was towards the west, when the connections were reversed towards the east, and the intermediate positions gave intermediate directions of motion.

An apparatus was afterwards made use of, which showed these results in a more distinct and satisfactory manner, somewhat resembling that above described for producing rotation in the wire about the magnet; the wire being suspended, so as to make with the vertical a greater angle than the dipping needle with the same; and here, the moment the contact was made, Mr. Faraday had the satisfaction to see the rotation commence precisely in the same manner as it would have done about the south pole of an artificial magnet.

These were the more important of Mr. Faraday's discoveries, but a number of other highly ingenious experiments were made by him at the same time, and are published in the same paper, (No. 23, *Journal of the Royal Institution*,) and in a note in the following number: some of them we shall have occasion to describe in the following general course, and for the rest we must refer the reader to the paper in question.

6. *Experiments of a miscellaneous nature due to several German philosophers and others.*

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32. So many persons were engaged in the pursuit of this new and interesting science, after the first announcement of the discovery by Professor Oersted, that it is nearly impossible to observe the proper order of discovery in point of date, we shall therefore, in this place, mention several miscellaneous experiments made about this time by different authors; but as most of these will occur in the general course, a very short notice of each will be sufficient.

. Yelin.

33. M. le Chev. Yelin discovered, independent of what had been done in Paris, the effect of enclosing a needle within a spiral wire, both by the discharge of the electric apparatus by sparks, and by galvanism. These results were published in the *Allegemeine Zeitung*, December 2, 1820.

r. Bockman.

34. Mr. Bockman made experiments on spirals of different diameters; increasing the diameter from the smallest size to thirteen inches, no perceptible diminution of effect was observed; but it was much impaired when the diameter was thirty-four inches, and scarcely any power remained, when it was increased to eighty-four inches.

M. Von Buch.

35. M. Von Buch, of Utrecht, corrected an error in Mr. Oersted's first paper. Mr. Oersted says, that if the uniting wire be placed perpendicularly to the plane of the magnetic meridian, whether above or below it, the needle remains at rest, unless it be very near the pole; in that case the pole is elevated if the entrance be from the west side of the wire, and depressed when from the east. M. Von Buch points out, that this state of rest does not continue in two out of these four positions of the wire. When the connecting wire is below the centre of the needle, and the positive current is from east to west, the needle remains unmoved: when the current is from west to east, it performs half a revolution; on the contrary, the connecting wire being above the current from east to west, makes the needle turn half way round, while that from west to east leaves the needle unmoved. The author concludes, that this peculiarity escaped Mr. Oersted, in consequence of the little power in his first apparatus. This was, no doubt, the case, for nothing is now better established than this fact of the inversion of the needle in the cases alluded to, when the power of the wire exceeds that of the terrestrial directive force.

M. Von Buch also appears to have ascertained the effect of common electricity, in producing magnetism, without a previous knowledge of what had been done by others, and succeeded in producing the effect by a much smaller power than had before been employed for the purpose. He found that a strong discharge was not necessary, nor even a Leyden phial; but fixing a helix between the prime conductor of a machine and another insulated conductor, placing a steel needle in it, and then drawing sparks from the latter conductor, the needle became magnetic. One single turn of a machine, with two discs, eighteen inches in diameter, was sufficient to make the needle evidently magnetic.

M. de la Rive.

36. M. de la Rive, in the *Bib. Univ.* (March 1821,) describes a very pretty little apparatus for exhibiting some of the leading facts connected with this science. It consists simply of two thin strips, one of copper and another of zinc, connected by a wire soldered to each, the wire itself being wound into a spiral, and the whole attached to a cork, and immersed in diluted acid; by this simple machine, many curious and important facts may be satisfactorily exhibited, but as it will be described more at length in the general course, this notice will here be sufficient.

M. Moll.

37. M. Moll, of Utrecht, in three letters to the editor of the *Journal de Physique*, the first dated March 23, the others without date, gives an account of some experiments made to ascertain the relative power of a battery consisting of many plates, and one of two large plates only. The large apparatus consisted of a narrow trough of copper, containing a plate of zinc, presenting near four square feet of surface: the smaller apparatus was one consisting of plates, four inches square, put together in Dr. Wollaston's manner, with the copper round the zinc. With the large apparatus, M. Moll remarked, that the magnetic power was very great, when the connecting wire was of considerable thickness, (two-tenths of an inch;) but when a platina wire, much smaller, was used, ($\frac{1}{100}$ of an inch,) the power diminished considerably. With a copper cylinder, however, about an inch in diameter, the power was diminished: no chemical action could be obtained by this apparatus, on making the connection with saline solution, or tincture of litmus, though the magnetic effects were very powerful. In making the comparison between this apparatus, and that with smaller plates and cells, thirty-six pair of the latter were taken; so that an equal surface was used in both instruments. These being put into action by the same acid, and the connecting wires being similar, that of the two plates made the needle deviate from 60° to 70° from the magnetic meridian; while that of the small plate battery made it deviate only 12°. The decomposing power of the small plate battery was very considerable, and M. Moll draws the conclusion, that the apparatus with cells produces chemical effects, while its magnetic action is very little; while the single plates have scarcely any chemical effect, though their magnetic power be very great.

M. Moll also remarks, that the positive and negative state of his single plates is in opposition to the states of a battery of many plates, inasmuch as the zinc pole is negative, and the copper pole positive. He found the position of the magnetic needle near his wire the reverse of what it was near the wire of a battery of many plates; for when the wire extended from the zinc pole, north, to the copper pole, south, a needle placed beneath turned towards the west instead of the east, and above, in the contrary direction. The cause of this difference will be readily seen, when it is remembered that M. Moll was using the wire that connected the zinc and copper plates of the *same* pair, and not of *different* pairs; so that, in fact, his connecting wire was in the inverse direction of those used to connect between the poles of a battery with four or more plates. This fact, as we have seen, (art. 9,) was noticed also by Oersted.

38. It remains now only to notice a few of the new

experiments which followed, and were dependent on those of Mr. Faraday. We have seen that this gentleman succeeded in making a galvanic wire rotate about a magnet, and then a magnet about the wire, and lastly a wire about the pole of the terrestrial magnetism, in any place. Pursuing the ideas thus developed, M. Ampere succeeded in causing a magnet to revolve on its own axis, by passing the galvanic current through it; Mr. Barlow produced a similar rotation in the galvanic wire, and some other rotations of rather a curious nature, which will be described as we proceed; and lastly M. Ampere proposed a very small and compact combination, which exhibited the rotatory property of the wire without the aid of any other galvanic apparatus than the machine itself. This also is described in the general course.

7. *Experiments by Professor Cumming.—First series.*

Experiments by Professor Cumming. First series.

39. Professor Cumming's experiments embraced all those which had been previously published, at the time when he commenced, but we shall only mention those which brought to light some fact not before known. The apparatus he employed was a single pair of zinc and copper plates, having two feet and a half surface, with conducting wires of copper; in the first instance, of one-fifteenth of an inch in diameter, but which he afterwards varied, in order to examine the effects due to different dimensions of the conducting arc. These we shall speak of as we proceed; at present it will be better to follow the order in which the experiments are reported. The first object of the author was, to ascertain the actual direction of the force by which the needle was disturbed; for this purpose the conducting wire was bent into a circle, and two delicate needles were used, one horizontal and one vertical, or suspended like a dipping needle; and in this way Professor Cumming discovered what has since been observed by other philosophers, and had, indeed, been previously observed, that the tendency of the electro-magnetic force is to place the needle transversely to the wire, a position which it actually took up, when the needle was neutralized so as to destroy or counteract the natural directive power of the earth upon it.

While carrying on these experiments the author found, that when the needle was placed within a conducting circle, the effects were much greater than when a single wire was employed, and this suggested to him the idea of constructing an apparatus for examining small galvanic effects, which he calls a galvanometer: it consists in placing a needle within a circular or square conducting wire, of two or more coils, and by neutralizing the terrestrial direction when necessary; we shall describe this, or a similar instrument, as we proceed; it is only spoken of here in order to mark the time of the invention, April 1821, as a foreign claimant of later date has recently appeared in some of the Foreign and English journals.

Professor Cumming observes, after mentioning the effect produced by so small an apparatus, "it may seem singular, that in Professor Oersted's earlier experiments, the effects were barely apparent, owing, as he imagined, to the feeble power of his battery; the reason of this he afterwards discovered to be, that the magnetic effect was dependent, not on the intensity, but the quantity of galvanism evolved; but he does not seem to be aware of the extent to which this observation may be applied. My first experiments were made with a battery of 220 double six-inch plates, possessing very powerful effects, both electrical and chemical, yet its influence on the needle was scarcely perceptible. One of these plates taken separately caused a deviation of nearly 80°. It is evident then, that though the circuit be complete, much of the magnetic influence is destroyed by the same circumstances which generates the electrical effects. This can be no other than the tension produced in consequence of the obstruction presented to the free passage of the galvanism, by the fluid interposed between each pair of plates; magnetism, therefore, cannot be properly considered as the effect of voltaic electricity, but of galvanism in its original form."

On the e fects of different lengths conducti wire.

40. Professor Cumming next proceeded to examine the effect of wires of different lengths and thicknesses; he found that the greater the diameter, the greater the disturbing power, and that the deviation increased with the diameters, although their lengths increased at the same time; and this law continued even with a single pair of plates, until the wire was larger than one-thirtieth of an inch; and in one case, when the connecting wire was supplied by a copper ball, a foot in diameter, the effect was still very visible. The author next endeavoured to ascertain the difference of effect between placing the pair of plates at greater or less distances from each other, and found that the tangent of the needle's deviation in these cases, varied very nearly as the square root of the distances in question. These experiments will, however, be best given in the author's own words.

41. "In using the magnetic needle as a measure of galvanic effects, we may either observe the deviation at a standard distance of the connecting wire from the needle, or assume a standard angle and measure the distance. The latter method seems to have the advantage, as enabling us to use a smaller, and therefore a more delicate needle, with this additional convenience, that the scale is increased in proportion as the length of the needle is diminished. I therefore constructed an instrument, having a connecting wire fixed upon a moveable slide, divided into inches and tenths, to which a vernier might be added, if necessary. My first object was to ascertain the divisions on the scale, corresponding to variations in the angle of deviation; for this purpose the moveable wire was placed at different distances from the needle, increasing in arithmetical progression, and the corresponding deviations were observed. As the effects decreased very rapidly during the galvanic actions, the experiments were made as quickly as possible, proceeding from a distance of half an inch to ten inches and a half, and again returning to the first distance. On taking the mean of several trials made in this manner, I found that the tangent of the deviation varies inversely as the distance of the connecting wire from the magnetic needle." We have already explained that the deviation varying according to this law, when the wire is of considerable length, answers to the law of the inverse square of the distance between particle and particle.

42. "It is well known, that in a galvanic arrangement intensity is given by the number, and quantity by the magnitude of the plates; but I am not aware that any notice has been taken of the effects produced by varying their distances from each other. On placing

a moveable plate of zinc opposite a fixed plate of copper, I found that, on diminishing the distance, the deviation of the needle, placed under their connecting wire, continued to increase until they were in actual contact. The law of that increase, ascertained by the method I have just mentioned, was such, that the tangent of deviation varied inversely as the square root of the distances of the plates. In the construction of a voltaic series composed of many plates, the advantages to be obtained by placing them very near each other, would be counterbalanced by the risk of their intensity becoming sufficient to penetrate through a small distance; but in using large plates, with an electricity of low intensity, it is obvious, that provided they are not in actual contact, they cannot be placed too near each other." By availing himself of this observation, Professor Cumming was enabled to repeat with a single pair of plates, the experiments of Ampere and Arago, which were supposed to require great power.

Professor Cumming, with the assistance of Dr. Clarke and Mr. Lunn, was the first to produce electro-magnetic effects from the electricity of the atmosphere, by the usual apparatus, an electrical kite. See the *Transactions of the Cambridge Philosophical Society* for 1821.

8. *Mr. Barlow's experiments on the mathematical laws of electro-magnetism.*

Mr. Barlow's experiments on the mathematical laws of electro-magnetism.

43. All the experiments that had been made on the subject of electro-magnetism, from the first discovery of that power by Mr. Oersted, seemed to indicate a strong affinity, although not a complete identity, between the simply magnetic and the electro-magnetic forces; or, if the identity be admitted, still a certain difference must be conceived to have place in the modes of action.

In a work entitled *An Essay on Magnetic Attractions*, &c., the author had attempted to reduce the laws of induced magnetism to mathematical principles, and to render the results susceptible of numerical computation, the mass of iron and its position, with respect to the compass, being given; and he was now desirous to establish, on similar principles, the law of electro-magnetism; but it was some time before he was able to construct an apparatus convenient for the purpose. Having, however, at length effected this necessary preliminary to his satisfaction, he proceeded to make the course of experiments, and to undertake the investigations which form the subject of the present section.

Having repeated, very carefully, all the experiments of Mr. Oersted, MM. Ampere, and Arago; of Sir H. Davy and Mr. Faraday, with some others, suggested by the results thus obtained; and having attentively considered all the peculiarities of action thus developed, he was led to consider that all the apparently anomalous effects produced on a magnetised needle by the action of a galvanic wire, might be explained by the admission of one simple principle; viz. *that every particle of the galvanic fluid in the conducting wire acts on every particle of the magnetic fluid in a magnetised needle, with a force varying inversely as the square of the distance; but that the action of the particles of the fluid in the wire, is neither to attract nor to repel either poles of a magnetic particle, but a tangential force which has a tendency to place the poles of either fluid at right angles to those of the other; whereby a magnetic particle, supposing it under the influence of the wire only, would always place itself at right angles to the line let fall from it perpendicular to the wire, and to the direction of the wire itself at that point.*

The author made no attempt to illustrate the mechanical principles by which such an action might be produced; he only undertook to show, that if such a force be admitted, all the results obtained from the reciprocal action of a galvanic wire and a magnetised needle may not only be explained but computed, and that the results agree numerically with experiments.

44. The galvanic machine which he employed, is constructed after the principle of Dr. Hare's calorimoter, differing from his only in the mechanical contrivance for lowering and raising it out of the fluid: it consists of twenty zinc, and twenty copper plates, each ten inches square; but it possesses a power far beyond what is requisite for making every experiment connected with this branch of philosophy.

Machine described. Fig. 10.

This machine is represented in fig. 10, pl. I. *a*, *b*, *c*, *d*, *e*, *&c.* is a pretty strong frame of wood, intended to carry the forty plates which are arranged as follows: on a stout strip of copper, at the back of the cross bar *k l*, are soldered, by their middles, ten zinc plates, and to another similar strip of copper are soldered, in like manner, ten copper plates; which are held in their respective places by nuts screwing on the ends of screw pins attached to the strips of copper, and passing through the cross bar, as seen in the figure; the two strips of copper having an opening of half an inch nearly between them. The other twenty plates, ten copper and ten zinc, are soldered in the same way to one copper strip the whole length of the frame, and screw-bolted to the corresponding cross bar of the frame on the opposite side, the ten copper first, and then the ten zinc; they are then arranged, so that there is one copper and one zinc, alternately, throughout the series; the plan of this combination is shown more particularly in (fig. 10, *a*) *z*, *p*, are the two poles, which consists of hollow tubes of copper, soldered to the copper and zinc plates, which are the inside ones of the front row.

Fig. 10, a.

Into these tubes are inserted the ends of the conducting wire, when any experiments are to be made, the latter just fitting the tubes, so as to give a great freedom of motion, and yet such as to preserve a good contact.

A B C D E is a strong wooden box lined with copper, its purpose being to contain the acid into which the plates are immersed for experiment; it is two feet in length, sixteen inches in breadth, and nineteen inches deep. F G H I is a frame attached to the side of the box, having a cross-piece at top supporting a winch and iron axis, to which, in the middle, is attached a piece of catgut, which, passing over pulleys or rollers at the end, descends and receives into nooses, at the ends, the extremities of an iron bar which passes through the copper handles H H, and through two long slips cut in the upright pieces, from the top to the bottom. The axle is furnished with a racket wheel and catch behind. By this contrivance the experimenter may lower the plates into the fluid, and raise them again at pleasure: an object of importance, because the machine loses its power, if kept long immersed. It moreover possesses the advantage of enabling the experimenter to immerse the plates, more or less, at his pleasure, the catch and racket wheel preventing its running down. The table T, in front, may be let down or fixed up like the leaf of a table: when up, it serves as a support for the apparatus on which the experiments are to be made. The other part of the apparatus, peculiar to the experiments, is shown in fig. 11, A B, is an upright stand, placed near the poles of the battery; *a b*, *c d*, are two staples of stout copper wire, driven into the upright, the two ends at *b* and *c* passing quite through, as shown at C and Z; and on which two wires are fastened by spiral turns, and with which the communication is made with the poles of the battery; *e f*, *g h*, are two copper wires of the same dimension as the staples, each four feet long, having their ends flattened and drilled so as just to enable them to slide freely upon the wires *a b*, *c d*, and the vertical wire *f h*, also four feet in length, which passes through a hole in the top of the table F G H I, and so tight as to render it perfectly fixed. On the plane of the table, which is two feet square, the circle N E S W is described about the centre *o*, and divided into the points of the compass and smaller divisions; N S, is an index or box ruler, through which the wire *f h* passes, so that the former may be turned freely about the latter, and set to any proposed azimuth. On this ruler is placed the small compass *c′*, by means of which the deviation at any time may be taken; *c″* is another compass placed on the top of the support L *c″*, and is intended to remain fixed in its place, in order to serve as a standard for estimating and comparing the power of the battery at different times.

Fig. 11.

Nature of the experiments described.

45. For the principal experiments this apparatus is placed so that the plane of the rectangle of wires is perpendicular to the magnetic meridian; because in this position, the horizontal wires being east and west, they have no effect in deflecting the needle from its direction, (at least there is only one exception to this, which will be noticed hereafter,) and consequently, all the effect produced upon the needle during the rotation of the index in the circle N E S W, is due to the vertical wire only, except so far as the horizontal wires may increase or diminish the directive power of the needle. This, however, in the cases to which we shall refer is very inconsiderable.

But in order that we may know precisely what part of the change of deviation between one situation of the compass and another is actually due to that change of position, recourse must be had to the standard compass, which always remaining fixed in its position, may be used as a constant indicator of the strength of the battery.

The vessel which contains the dilute acid, into which the plates were immersed, holds nearly twenty gallons; and the experiments were begun with little more than twelve gallons; moreover the plates were not, in the first instance, let down to their lowest point. The intensity, shown by the standard compass after the connection had been made some minutes, was noted; and by breaking off and making the contact anew, this same intensity occurred again, the power being always strongest when the contact is first made; then, when the standard compass returned to its former bearing, the observation with the other compass was taken; the contact broken and renewed, and so on as long as the battery retained sufficient power. When this failed, the plates were lowered a little more, the power thus increased, and the observations resumed, till at length the plates being wholly down, and the power too weak, recourse was had to a supply of more dilute acid; by which means a tolerably steady action was kept up, longer than was necessary for any series of experiments of this kind.

Having thus explained the means employed, and the precautions adopted, to ensure accuracy, we shall proceed now to explain the principles of computation, and to compare the numerical results thus obtained, with those derived from experiments.

46. According to the hypothesis, (art. 43,) if we conceive the wire, in the first instance, to be vertical, and the compass placed to the north or south of it, and opposite its middle point, the centre of action will lie in the horizontal plane, and at right angles to the natural horizontal direction of the needle. The latter, therefore, (which, for simplicity sake, we shall at present consider as indefinitely short, with regard to the distance,) will, at either of those points, be acted upon by two rectangular forces; viz. the galvanic force in an east and west direction, and which we may denote by f, and the natural magnetic or directive force m; consequently, according to the principle of forces, the resultant will be expressed by $\sqrt{(f^2 + m^2)}$ and the angle which it makes with the natural direction of the needle, being called Δ, we shall have

$$\tan \Delta = \frac{f}{m} \qquad (1)$$

Hence the magnetic force being constant, the tangent of the needle's deviation at the north or south will be a correct measure of the galvanic power.

We have thus a principle, by means of which we may verify a part, at least, of our theory by experiments.

For example; since, by the supposition, every particle of the galvanic vertical wire acts inversely as the square of its distance from a given point, we ought to find a determined relation between the tangent of deviation and the length of the wire; or the length of the wire remaining constant, between the tangent of deviation and the distance, provided always that the intensity of the battery remain constant.

The apparatus explained furnishes the means of making both these comparisons. For the sliding horizontal rods will enable the experimenter to shorten the vertical conducting part of the wire; and in the second case, it is only necessary to slide up the compass to different distances, which may be done so quickly that it will not be necessary even to have recourse to the standard compass.

It is fortunate also that the calculation here alluded to, is of the simplest kind. For denoting the length of the wire by $2\,l$, and the distance of the compass by d; assuming also x as any variable length, the corresponding elementary action at this distance will be $\frac{\dot{x}}{d^2 + x^2}$, and the sum of these actions will be

$$\int \frac{\dot{x}}{d^2 + x^2} = \frac{1}{d} \text{ arc tan } \frac{x}{d}$$

which vanishes when x vanishes; and which therefore when $x = l$, and the two lengths are included, becomes

$$\frac{2}{d} \text{ arc tan } \frac{l}{d}$$

consequently if we denote the deviation, as we have done above by Δ we ought to find this force vary inversely as tan Δ or

$$\cot \Delta \left\{ \frac{1}{d} \text{ arc tan } \frac{l}{d} \right\} = \text{a constant quantity.}$$

The following are a few out of numerous experiments of this kind which the author made and which were all found equally satisfactory.

Experiments to determine the magnetic deviation caused by a galvanic vertical wire at different distances. Length of vertical wire 36 inches.

Deviation by standard compass.	Distance of the other compass from the wire.	Mean[*] observed deviation, Δ	Value of $\frac{2}{d}$ arc tan $\frac{l}{d}$ = A	Constant product, A cot Δ
25° 0′	12 inches	5° 37′	18·772	190880
Ditto	8 ditto	11 15	34·100	171432
Ditto	6 ditto	16 30	47·712	161062
Ditto	4 ditto	26 30	77·500	154440
			Mean..	164728

[*] That is, the mean of two observations at each station of the compass; the contact being changed. The same is to be understood of the deviation with the standard compass.

When it is considered that these observations were made on a compass needle only one inch in length, and that the divisions extended only to quarter points, it is impossible to expect a closer approximation. The needle and card, however, being delicately suspended, and the latter very distinctly divided, the observations might be depended upon to the nearest *degree*; for by means of a strong magnifying power the observer could always bisect and trisect the quarter points without any very sensible error.

Experiments to determine the magnetic deviation caused by a vertical galvanic wire; the length being varied, but the distance constantly 9 inches.

Deviation by standard compass.	Length of vertical wire.	Observed deviation, = Δ	Value of $\frac{2}{d}$ arc tan $\frac{l}{d}$ = A	Constant product, A cot Δ
——[*]	36 inches	22° 30′	63·450	15318
——	24 ditto	18 16	53·133	16097
——	16 ditto	12 0	41·633	19557
——	12 ditto	8 25	33·683	22764
			Mean..	18220

[*] The standard compass cannot be used in these experiments, because the wire by which it is deflected is necessarily shortened with that on which the observations are made.

These results (except the last) although not so uniform as the above will be found, notwithstanding as nearly so as we have any reason to expect, particularly as the standard compass could not be employed.

Mr. Barlow, however, is inclined to attribute the discrepance between the observed deviation and the computed, as the vertical wire shortens, to the approach of the horizontal wire, which has a tendency to increase or decrease the directive power of the needle, according to the pole with which the wire is connected, (as will be seen as we proceed,) and thereby rendering the action of the vertical wire more or less effective, according to the circumstances of the connection. (See art. 51.)

47. Having thus far verified his hypothesis by experiment, he next proceeds to the consideration of the deviation in different azimuths.

Fig. 12. Deviations in different azimuths.

Let Z (fig. 12,) represent the horizontal section of a vertical wire proceeding from the zinc end of the battery downwards, o a particle of the magnetic fluid whose natural direction is in $n\ s$, join Z o, and draw $r\ t$ perpendicular to Z o; then, according to the hypothesis, the direction of the force excited by the wire Z, will be in the line $r\ t$. Now the intensity of this force to turn the particle about o, will vary as $\sin \angle\, t\, o\, n$, or as $\cos S Z o$, and its intensity in the line $n\ s$, will vary as $\sin S Z o$, which latter force will be additive to the directive power of the terrestrial magnetism. Let the latter force on the horizontal needle be called m, and the galvanic force in $r\ t = f$, also the angle $S Z o = \phi$, S being the south point of the horizon.

Then the particle o, will be urged by the two rectangular forces,

$m + f \sin \phi$ in the direction $n\ s$

$f \cos \phi$ in the direction perpendicular to $n\ s$,

consequently, denoting the angle of the resultant, or the deviation of the particle from the line $n\ s$ by δ, we shall have from the known principle of forces

$$\tan \delta = \frac{f \cos \phi}{m + f \sin \phi} \qquad (2)$$

Let Δ denote the deviation of the needle at the south point; then, from what has been already demonstrated (equation 1)

$$f = m \tan \Delta$$

which being substituted for f in the above equation, reduces it immediately to

$$\tan \delta = \frac{\cos \phi}{\cot \Delta + \sin \phi} \qquad (3)$$

From which equation (the deviation Δ being supposed known) the deviation δ at every other azimuth may be computed.

Formula 3 compared with experiment.

48. This formula is as comprehensive as it is simple, and indicates by the changes of the signs in $\sin \phi$ and $\cos \phi$, a variety of cases, the whole of which the author most satisfactorily confirmed by experiments. These may be stated as follow:

First, $\cot \Delta$ may be greater, equal to, or less than unity, accordingly as the observed deviation at the south is less, equal to, or greater than four points, or 45°. This consideration leads to three distinct cases.

Case I. *when* $\cot \Delta > 1$.

Here the denominator of the formula is necessarily positive throughout the circle. In the first quadrant of which, $\sin \phi$ and $\cos \phi$ being both positive, $\tan \delta$ is also positive, and the deviation is all one way.

2. When $\phi = 90°$, $\cos \phi = 0$; and $\tan \delta = 0$; there is therefore no deviation at the east point.

3. In the second quadrant, $\cos \phi$ is negative, as is

also $\tan\delta$; the deviation is therefore now the contrary way, but it is the same in quantity in all equidistant situations north or south of the east.

4. At the north point, $\sin\phi = 0$, $\cos\phi = -1$, and we have

$$\tan\delta = -\tan\Delta$$

the deviation is therefore the same as at the south, but in an opposite direction.

5. In the third quadrant, $\cos\phi$ is still negative, as in the second, but $\sin\phi$ is also negative, and therefore the deviation, although of the same kind in direction as in the second quadrant, is greater in its amount, the denominator being less.

6. At the west, the $\cos\phi$ vanishes, $\tan\delta$ becomes zero, and the needle again resumes its natural direction.

7. In the fourth quadrant, $\cos\phi$ again becomes positive, the deviation changes in its quality, but is the same in quantity as in the third quadrant.

CASE II. *when* $\cot\Delta = 1$.

8. Here the results are precisely the same in the four quadrants with respect to direction, as in those above explained; except that at the west point, where $\sin\phi$ and $\cot\Delta$ being each equal to unity, and with contrary signs, the denominator vanishes with the numerator, and the needle is indifferent to any direction.

CASE III. *when* $\cot\Delta \angle 1$.

9. Here in the first two quadrants the deviation has the same character as in the preceding cases. But in the third quadrant, the denominator of the fraction vanishes before the needle reaches the west point, $\tan\delta$ becomes infinite, and the deviation is 90°; that is, the needle will stand east and west.

10. For the remainder of this quadrant, $\tan\delta$ is *plus*, and the character of the deviation changes, till at the west point the needle is found inverted.

11. From this point $\cos\phi$ becomes positive, but the denominator being negative, $\tan\delta$ is negative, and remains so till it becomes infinitely negative, as on the other side of the west, and the deviation is 270°.

12. Lastly, from this point to the south, the denominator is positive, and $\tan\delta$ has the same sign as at first, and at the south point resumes its original deviation, provided the intensity of the battery has been preserved constant.

To illustrate this last case by an example, let us suppose that the deviation at the south point is greater than 45°, as for instance 50°, then since $\cot 50° = 0{\cdot}83909$, and $\sin(180° + 57°\ 2') = -0{\cdot}83914$; the denominator will vanish when the compass is placed 57° from the north towards the west; the $\tan\delta$ is therefore infinite, or the needle will at this place stand east and west.

Proceeding on towards the west, the deviation will increase more and more till, at the west point itself, the needle will be found inverted. At 57° from the south, or 33° from the west towards the south, the denominator again vanishes, and the needle stands west and east; from which position the deviation decreases till it becomes 50° again at the south point as at first.

Hence it appears that in passing the index which carries the compass from the position west 33° N. to west 33° S., that is through 66° only, the needle ought to make a complete semi-revolution on its pivot; whereas if we pass the index the other way, viz. through the north, east and south, we must move it through 294° to produce the same motion in the needle. A single trial will show how correctly this theoretical deduction accords with experiment.

In the above case the needle makes a complete revolution on its pivot while it is carried round the wire; but this will not happen if the deviation at the south be less than 45°. Let us, for example, suppose it to be 40°; then $\cot 40° = 1{\cdot}19175$, and $\sin\phi$ is never greater than $+1$, or less than -1; consequently the denominator will not become zero. In this case the deviation will be the greatest when

$$\frac{\cos\phi}{\cot 40° + \sin\phi} \text{ is a maximum,}$$

which happens when $\sin\phi = -\tan 40°$, viz. at 33° from the west towards the north and south; but in passing the index through this arc, the north point of the needle will not, as in the former instance, pass through the south, but will fall back towards the north, passing through it as the index passes through the west. Here again the theory is most satisfactorily confirmed by observation.

It is proper, however, to caution the reader that to ensure success in these experiments, it is necessary to have a short needle, and to work at as great a distance from the wire as the power of the battery will allow of; because the above deductions have been made by supposing the length of the needle inconsiderable in comparison with the distance and length of the wire.

The following is one series of numerical results derived from the preceding formula, with the corresponding observations.

Table o numeric results.

Experiments on the deviation of the needle caused by a vertical galvanic wire at different azimuths, the deviation at the south point being 16° 30′, *and the standard compass showing always* 25°.

Azimuths.	Value of $\tan\delta = \dfrac{\cos\phi}{\cot\Delta + \sin\phi}$	Corresponding angle of deviation.	Observed deviation.	The same as observed in points and quarter points.	
		° ′	° ′	p.	qp.
South E.	+ ·296	+16 30	+16 30		
S. 2 points E.	+ ·245	+13 46	+14 4	1	1
S. 4 points E.	+ ·173	+ 9 49	+ 8 26	0	3
S. 6 points E.	+ ·089	+ 5 6	+ 5 37	0	2
East	000	0 0	0 0	0	0
N. 4 points E.	− ·089	− 5 6	− 5 37	0	2
N. 4 points E.	− ·173	− 9 49	− 8 26	0	3
N. 2 points E.	− ·245	−13 46	−14 4	1	1
North	− ·296	−16 30	−16 47	1	2
N. 2 points W.	− ·389	−21 16	−22 30	2	0
N. 4 points W.	− ·265	−14 51	−14 4	1	1
N. 6 points W.	− ·156	− 8 53	− 8 26	0	3
West	000	0 0	0 0	0	0
S. 6 points W.	+ ·156	+ 8 53	+ 8 26	0	3
S. 4 points W.	+ ·265	+14 51	+14 4	0	3
S. 2 points W.	+ ·389	+21 16	+22 30	2	0
South	+ ·296	+16 30	+16 47	1	2

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49. Although the aberrations in these results are greater than could be admitted in experiments which allowed of more accurate means of observation, yet they are such as may be adduced as a confirmation of the hypothesis that has been advanced.

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g results.

It may be proper here to observe, that the sign of plus or minus prefixed to the angle of deviation, is wholly arbitrary. We have called it *plus* when the deviation is easterly, and *minus* when it is westerly.

This sign however being thus fixed, it is necessary to give an indication of the course of the needle as it is affected by the galvanic wire, which at present has only been stated in general terms; viz. that it has a tendency to arrange itself at right angles to the line joining the nearest point of the wire and its axis.

To conceive this effect more particularly, the author directs that the reader should consider himself as a part of the galvanic circuit, or coinciding in position with it, having his head towards the zinc end of the battery, and his face to the needle; then the effect will be to carry the north end of the needle placed before him always to his left hand, when the apparatus consists as in this case of a simple combination of two plates; it is the reverse with a compound battery.

This is in all cases sufficient to remember, because it necessarily implies that the south end is carried to the right, and that if the wire proceed from the other extremity of the battery, the observer's direction will be reversed, as will also the motion of the needle, and the signs of the angles of deviation.

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50. We have at present shown no other application of the standard compass than that of its indicating an uniformity of power in the battery at the time of registering the observation; it may, however, be equally useful in other cases. For example, let us suppose it to be placed (as in the experiments reported above) to the north of the wire, and let its deviation at any given intensity of the battery be D, while that of the other compass at the north or south is Δ, and let its deviation with a different intensity be D′, and the corresponding deviation with the other compass be Δ'; then it is obvious from what has been stated, that

$$\tan D : \tan \Delta :: \tan D' : \tan \Delta'$$

consequently, if the power of the battery between any two observations is such as to alter the deviation of the standard compass from D to D′, that of the principal compass will be found from the equation

$$\tan \Delta' = \frac{\tan \Delta \tan D'}{\tan D}.$$

We have therefore only to introduce this value of $\tan \Delta$ into our general equation,

$$\tan \delta = \frac{\cos \phi}{\cot \Delta' + \sin \phi},$$

which will thus become

$$\tan \delta = \frac{\cos \phi}{\dfrac{\tan D}{\tan \Delta \tan D'} + \sin \phi};$$

a formula which is applicable to all degrees of intensity.

Progress of
Discovery.

51. Let us now examine the circumstances attending the deviations caused by a horizontal wire placed in the magnetic meridian.

Fig. 13.

The action
of a hori-
zontal
needle
examined.

In this case conceive S E N W (fig. 13) to represent a vertical circle in the plane of the section of the wire, and corresponding with its middle point, E and W being its east and west points. Let *o* be a magnetic particle or a horizontal needle, the direction of which is perpendicular to the plane S E N W. Let the force in the line *r t* be denoted by *f* as before, and call the angle S Z *o* = ϕ'. Resolve *f* into the two rectangle forces, $f \sin \phi'$, $f \cos \phi'$; the former of which being perpendicular to the horizon will only affect the inclination of the needle; but the other force, $f \cos \phi'$, being horizontal, and in an east and west plane, will be wholly effective in producing its deviation.

Let Δ be the deviation at S, which will be the same whether the wire be horizontal or vertical, because in both cases the tangential force is horizontal and perpendicular to the needle.

Consequently, as in the former case,

$$f = m \tan \Delta$$

and our two forces become

$m \tan \Delta \cos \phi'$, in the horizontal plane,
$m \tan \Delta \sin \phi'$, in the vertical plane;

the former, as we have seen, is the only one which affects the bearing of the needle, and is therefore the only one we have to examine.

From this we obtain,

$$\tan \delta = \frac{m \tan \Delta \cos \phi'}{m} = \tan \Delta \cos \phi';$$

and hence we learn, that as the compass is carried round the wire in a vertical circle, the tangent of the deviation of the needle will vary as the cosine of the angle S Z *o*.

This cosine being zero at the east point,* the tangent δ vanishes and the needle stands in its natural direction, but will be inclined downwards by the force

$$\tan \Delta \sin \phi'.$$

Beyond the east point $\cos \phi'$ becomes negative, the sign of $\tan \delta$ changes, and consequently the deviation is now the contrary way. At N, $\cos \phi = -1$, and $\tan \delta = -\tan \Delta$, we have therefore here the same deviation as at first, but in an opposite direction.

In the next or third quadrant, $\cos \phi'$ is still negative, and the deviation is the same both in quantity and direction as in the second quadrant. At the west point $\cos \phi'$ again vanishes, and the needle returns to its proper direction. In the fourth quadrant $\cos \phi'$ is positive, and the deviation is the same both in quantity and direction as in the first quadrant. There is not therefore in this case the same kind of anomalous deviation which takes place in the vertical wire.

The other force $\tan \Delta \sin \phi$, which affects the needle's inclination, is greater at the east and west points; it is nothing in the zenith and nadir, and in all intermediate positions it varies as the $\sin \phi$. All these deductions are perfectly consistent with the general character of the observations of Mr. Oersted, and other experimenters.

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* By the east point is meant that point in the circle which is to the east of the wire, and in the same horizontal plane with it.

It was at first asserted by Mr. Oersted that a horizontal wire arranged east and west had no power on the needle, except to disturb its inclination. But it ought obviously, according to the above theory, to produce the same anomalous action as the vertical wire in the case where $\cot \Delta$ is equal to or less than unity; because then the galvanic force being equal to, or exceeding the terrestrial directive force, it ought, when the two are opposite, to reverse the direction of the needle; and this will be found to be the case by applying the latter above the upper, or below the lower horizontal wire, when the former is connected with the zinc end of the battery, and the reverse with the opposite connection; it was, doubtless, the weakness of Mr. Oersted's machine that prevented him from noticing this action in the first instance. It is this effect to weaken or reverse the direction of the needle that we have alluded to in art. 46.

General remarks.

52. We might now proceed to a variety of other investigations for different directions of the wire, or even generally for every possible direction, and for a needle freely suspended and susceptible of motion in all directions; but as it would be difficult to submit the results to the test of numerical experiments, it would be useless to proceed with the investigation, as our results are necessarily only approximative; because we have throughout supposed the needle indefinitely short in comparison with the distance and length of the wire; but by this means the subject has been rendered perfectly intelligible to every one; whereas had we taken the actual case of the reciprocal action of every particle of the fluid in the wire upon every particle in the needle, and had been able to complete the investigation, it could only have been understood by a few mathematicians; at the same time the minute corrections thus introduced would not have been appreciable in the comparison of the results with experiments; these latter being necessarily both liable to small irregularities and difficult to observe.

It may also be observed, that we have hitherto supposed only one species of action in the galvanic wire; but it is highly probable that it is compound, and that while the north end of the needle is carried in one direction, by the action we have supposed, the south end is carried in an opposite direction; not merely as a consequence of the first force, but by a distinct power. This will not, however, in any respect affect our investigation; because both forces lead to similar results.

We have seen a precisely analogous instance in our investigation of the laws of induced magnetism, where it appears that we obtain exactly the same results, whether the magnetic fluid is considered as simple, and acting equally on each extremity of the needle, or as compound, and acting reciprocally on both; and it was only for the sake of certain analogies, (explained in our section on Terrestrial Magnetism,) which the author was desirous of preserving, that he was induced to adopt the latter hypothesis. Similar reasons may also render it necessary, in this case, to admit the existence of a compound action in the galvanic wire; but which, as we have already stated, will in no respect affect the preceding investigations.

We are well aware of the difficulty of conceiving the mechanical principles by which such a tangential force, as is here assumed, can operate; but on the other hand it must be conceded, that the simple power of attraction is equally difficult to conceive, and that we admit it, not from having any idea of the *modus operandi*, but because we find that it leads to results that are consistent with actual observations; and we have endeavoured to show, in the preceding pages, that the force we have assumed is admissible upon precisely the same ground. Barlow's *Essay on Magnetic Attractions, &c.*

53. These experiments furnish one striking fact, which must not be lost sight of, in forming a theory of electro-magnetism; they prove, incontestably, that to whatever mechanical principle the electro-magnetic action may be referred, the result of that action is a tangential force, which, between particle and particle, varies inversely as the square of the distance, and if nothing more is ever known of this principle, we shall be, perhaps, as well informed on this, as we are on most other physical subjects. What more do we know of the nature of gravitation, or universal attraction, or of simple electric and magnetic forces? In these, and in various other physical subjects, we are content to find the mathematical laws, without making useless inquiries concerning first causes; and it is highly probable, that after all that has been or may be written on the present subject, we shall be obliged to stop at the same point, and to leave the first cause as a matter too subtle for our comprehensions. At all events, we know that two currents of electricity in motion, impress by their mutual action a force differing very essentially from those commonly considered as electric, and which affects the magnetic needle according to the laws which have been stated in the leading articles of this section.

§ III. *Thermo Electric-Magnetism.*

1. *Professor Seeback's experiments.*

Professo Seeback' experiments.

54. The advances that had now been made, seemed to have nearly exhausted the subject, and to have elicited all the principle facts connected with the science of electro-magnetism; it had been demonstrated by what had been already done, that magnetism was produced whenever a current of electricity was made to pass through any conducting body, and some of the conditions and laws relative to the magnitude, length, temperature, &c., had been investigated by Sir H. Davy and Professor Cumming; the mathematical laws of this action had been satisfactorily developed by Mr. Barlow; Mr. Oersted and M. Ampere, had each laid down a theory, which, whether either of them were fully competent or not, to meet all the facts, served to generalize the greater number of them, and to reduce the action of magnets, and that of galvanic currents, to one general principle. But a new field was now opened to philosophical investigation, by the discoveries of Professor Seeback. This philosopher, a Member of the Academy of Berlin, discovered that an electric circuit may be established in metals, without the interposition of any liquid. The electric current is here established by merely disturbing the

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equilibrium of temperature. The apparatus for exhibiting this action is very simple, being formed of two arcs of different metals soldered together at the two extremities, so as to form a circle, or any other figure, as a rectangle, square, &c. The heat then being applied at one of the points of union, and the magnetic needle placed within the space included by the electric conductor, it is acted upon in a manner strongly resembling that which we have already described in the case of hydro-electric currents, but not always in the same direction. We have not been able to meet with any particular details of the first trials, and subsequent experiments of this ingenious philosopher, except so far as they have been described in the account given of the repetition and extension of them by Professor Moll, of Utrecht; we shall therefore copy this series of experiments as they were communicated by letter to the writer of this article, and as they appeared in the *Edinburgh Philosophical Journal*, No. xvii., and the reader will perceive how far Professor Seeback led the way, and to what length the results have been extended by the Utrecht Professor.

2. *Repetition and extension of the experiments of Professor Seeback, oy Baron Van Zuylen, Dr. Van Beek, and Professor G. Moll.*

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55. Professor Moll begins by observing, that "It was stated some time ago, by Professor Seeback, in some of the French and German scientific journals, that *antimony*, brought into proper contact with another metal, and *unequally* heated, would cause the magnetic needle to deviate from its meridian. With a view to ascertain this fact, and to investigate whether this property was restricted to antimony, or extended to other metals, the following experiments were made.

g. 14.

1. "A parallelopiped of *antimony* was procured, about fifteen inches long, and one inch square. This bar was prepared by treating crude antimony with sulphate of potash and tartrate of potash. A slip of copper was attached to both ends of the antimony, and bent, as fig. 14 indicates. It was kept in close contact with the antimony, by means of copper rings. This bar was laid in the direction of the magnetic meridian. A needle was placed on the antimony, as shown in the figure, and the ends N and S of the bar were successively heated by a spirit lamp. When the heat was thus applied to the south end S, the magnetic needle immediately and strongly deviated to the *east*. The extent of this deviation depends on the length, mobility, and strength of the needle. We have seen it as much as 60°. When the heat spreads more uniformly through the metal the deviation decreases, and the needle gradually returns to the magnetic meridian.

"Supposing the deviation to the *east* at his maximum, the lamp burning under the end S, facing the south, if then it be removed and placed under the end N, the deviation to the *east* will decrease, and it will change into a deviation to the *west*.

"In general, if the heat be applied under the north end of the bar, the needle will deviate to the west.

Fig. 15.

2. "It was then proposed to try whether cooling one end of the bar would produce the same effect as heating the other, and the apparatus was disposed as in fig. 15. The end N was cooled in some frigorific mixture, whilst the end S was kept in the hand. The needle deviated to the *east*, but, of course, not so strongly as when the difference of temperature of the ends is produced by heating one end of them.

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3. "The apparatus was then replaced as in the first experiment, and both ends heated by a spirit lamp. No deviation was observed; on removing the lamp under the *south* end, the deviation was to the *west*; and on removing the lamp under the *north* end, that under the south remaining, the deviation was *easterly*.

Fig. 17.

4. "Two bars of antimony were used, and the needle placed between them, as shown in fig. 17. If both the ends N and N′ were heated, the needle placed in c did not deviate. If the ends N and S′ were heated, the needle deviated to the west. If S and N′ were heated, the deviation was to the east.

Fig. 14.

5. "In this experiment, both ends of the bar of antimony were connected, not by copper but by zinc, as in fig. 14. The bent slip of zinc was fastened to the antimony by rings of the former metal. In order to make the experiment succeed, the oxide must be carefully removed from the place where both metals are in contact. If the end of the bar of antimony turned to the north, is heated, the deviation of the needle is westward, but much less than when the conjunctive slip is copper. By these experiments, Professor Seeback's statement is, we presume, fully confirmed.

Fig. 17.

6. "It then became necessary to inquire, whether antimony alone would act in this manner on the needle, or whether any other two metals, joined in the same manner, would produce similar effects. After some trials, the following apparatus was adopted. A thin slip of red copper of one-fourth of an inch in width, and a similar one of zinc, were bent, as in fig. 17, C D, being about eight inches in length. The ends of the two metals were rivetted together at A and B, and the whole placed in the magnetic meridian, and a needle in E. A spirit lamp was applied to the end B, turned to the north, and the needle deviated 10° to the *west*. If the whole was suffered to cool again to the temperature of the atmosphere, and the lamp was applied at A, the needle would deviate to the *east*.

7. "The apparatus being inverted, so as to have the zinc above, and the copper under the needle, then on heating the part B, turned to the north, the deviation was 10° to the east.

8. "The experiment was repeated with silver and zinc, instead of copper and zinc, as in fig. 17.

"The apparatus being thus situated, the deviation was to the *east*, if heat was applied to the end turned to the north; and to the *west*, if applied to the end turned to the *south*.

9. "It was thus evident, that the property mentioned by Professor Seeback, is not restricted to antimony, but that other metals, properly diposed, will produce the same effect."

Professor Moll goes on in his letter to describe some other experiments, but in which acids, instead of heat, were applied to produce the electrical current; these therefore belong rather to the hydro electric-magnetism, than to the thermo electric; but as several of the experiments have reference to the results obtained by heat, and as several others differ from the usual hydro electric experiments in this, that only one metal is employed, while it had always been hitherto supposed that two metals were necessary, we are disposed to continue the series in this place, although the remainder of the experiments may not be properly classed under the head of Thermo Electrics.

3. *Continuation of Professor Moll's experiments, in which the electro-magnetic action is excited, by means of an acid, and one metal only.*

Professor Moll's experiments with an acid, and one metal.

56. In continuation of his series from Experiment 9, above reported, the Professor states that General Van Zuylen here suggested a different way of applying the heat, and causing the deviation of the needle, in order to render the effects more striking.

Fig. 18.

Slips of copper and zinc were disposed as in fig. 18. The two ends of both metals were coiled up together, so as to form a spiral of several turns. This spiral was immersed in a cup containing water; and the whole was placed as in the figure. The needle was set upon the zinc, and sulphuric acid was then poured into the cup, and the needle deviated to the westward as much as 50°, or 60°, and sometimes even to 87°, according to its sensibility. *It is remarkable, that in this case, the deviation of the needle is the reverse of what it would have been if the heat of a lamp had been applied;* for, from the sixth experiment, it is clear, that the deviation would have been to the east, while, by using sulphuric acid and water, it is to the west; when the end turned to the south is dipped in the fluid, the chemical action between the acid and the metals, independently of the heat evolved, having such a powerful influence on the results of the experiments, it was deemed necessary to inquire whether *one* metal, with an acid to act upon it, would produce the deviation. With this view, a trial was first made with a metal and an acid, not strongly acting on each other.

Fig. 19.

10. A slip of copper, perhaps sixteen or eighteen inches long, was then bent, as in fig. 19, and the ends coiled up, and brought as close into contact as possible; the whole being, as usual, disposed in the magnetic meridian, the needle being inside the copper, and the coil to the south. If sulphuric acid is added to the water in the cup, there is no deviation of the needle perceptible. But then, if a bar of zinc be immersed in the fluid, and made to touch the copper, the needle deviates 10° or 12° eastward.

11. If, instead of sulphuric acid, nitric be employed, a deviation of the needle to the west is observable, as soon as the acid is added to the water.

12. The bent slip was now made of zinc, in the same manner as it was made of copper in fig. 19, as in the former experiment. The coil being turned to the south, and sulphuric acid poured into the cup, the effect was very strange. The needle, placed as in fig. 19, first deviated to the *east*, but soon after turned to the *west*. In that situation it remained for some minutes, and then gradually returned to the magnetic meridian. If a new quantity of acid be added to the fluid, a subsequent deviation is produced, the needle first turning *eastward*, and afterwards *westward*.

Whilst this deviation took place a bar of copper was introduced into the fluid, and made to touch the zinc. The needle began irregularly to vacillate, and actually was made to turn round several times on its axis.

Fig. 20.

13. The same experiment was repeated, but the ends of the zinc were made so as not to touch each other, as in fig. 20. As soon as the acid is added, there is a slight deviation to the east, to which succeeds a stronger one to the west. A bar of zinc is now introduced in the fluid, and successively made to touch the ends A and B. When this zinc touches the end A, the deviation increases to the east, but if it touched the end B, the deviation increases to the west. Both ends being joined by the zinc, the deviation is to the west.

Instead of a bar of zinc, another of copper is introduced, and successively made to touch the ends of the zinc. If it touches the end A, the deviation is to the west; if it touches the end B, the deviation is to the east; if both ends are joined by the copper, the needle wheels about its axis, turning first through the west.

14. The apparatus was then so far altered, as to connect both ends of the zinc by a bar of copper. This disposition was as follows: the needle A and B were united by a bar of copper C, extending between them, as shown by dotted lines. This part of the apparatus, as in the preceding, was turned to the south, and dipped in water. A thermometer proved the temperature of this water about 56°. When sulphuric acid was added, the needle immediately deviated strongly to the *east;* and as the temperature augmented to 92°, the deviation became strongly westerly.

Fig. 21.

15. Instead of zinc, iron was now made use of, and a hoop of three or four feet long, two inches wide, and one-tenth of an inch thick, was bent, as shown in fig. 21. The plane of this bent hoop was placed in the magnetic meridian, and two needles, one in C, and another in D, were so arranged as to have their directions in the same plane. Sulphuric acid was then poured on the water in the cup, and, instantaneously, the point of the needle turned 70° to the *east*. Soon after, this deviation decreased, and became as strongly *westerly*, and remained so for several minutes. It then slowly returned to the magnetic meridian: when returned in this situation, *nitric acid* was added to the sulphuric acid water already in the cup; by these means the deviation became 90° to the east, and remained so for a considerable time. Then a lump of zinc was thrown in the acids, and the *easterly* deviation changed to a *westerly*. After all this a piece of copper was introduced, which made the needle turn on its axis. While the needle placed in C was thus deviating, the other in D followed in a contrary direction. Thus, if the needle C deviated to the *east*, the needle D deviated to the *west*. In general, the deviations of the exterior needle D were about *one half* of those of the interior one C. If, for example, C *would* deviate 90° to the *east*, the deviation of D was 45° to the east.

4. *Experiments of Professor Cumming.—Second series.*

Professor Cumming experiments. Second series.

57. It has been stated, that Professor Seeback, of Berlin, first discovered that electricity or electro-magnetism might be developed by heat, but that we were not in possession of his actual experiments. This seems also to have been the case with Professor Cumming, who appears to have had nothing to guide him in the long series of ingenious and important experiments we are about to detail, but the following very slight notification. "Take a bar of antimony, about eight inches long and half an inch thick, connect its extremities by twisting a piece of brass wire round them, so as to form a loop, each end of the bar having several coils of the wire. If one of the extremities be heated a short time by a spirit lamp, electro-magnetic phenomena may be exhibited in every part of it."

This, as we have said, was all the hint furnished, relative to this new species of electro-magnetism, and to which we are indebted for the several important facts developed by the author, in his memoir, published in the *Transactions of the Cambridge Philosophical Society* for 1823.

58. The first object was to ascertain whether the coils, described as being made about each end of the bar, were actually necessary, as in some other electro-magnetic experiments we have described, or whether contact only was necessary. It was soon determined that the mode of attaching the wire to the bar was immaterial, provided only that a good contact was obtained. Instead of the coils, therefore, the wire was attached to the bar, by rivetting, soldering, or by casting the bar on the wire, as was found most convenient.

59. The next inquiry was, is the effect described due only to antimony, or is it common to other metals? This query was answered by showing, that not only all the metals, including fluid mercury, but likewise plumbago and charcoal, and some, at least, of the metallic sulphurets, possess the property of exhibiting electro-magnetism by heat, differing, however, both in quantity and quality. But before the reader can properly comprehend the nature of the experiments, from which the author drew his results, it will be necessary to describe the instrument which has been already mentioned in art. 39, i. e. the *galvanometer*, or *galvanascope*, for rendering obvious very small electric forces. This is represented in fig. 23.

Fig. 23.

A K are tubes filled with mercury, to be connected with the galvanic plates.

A B C D E, &c. a wire placed in a spiral form round the compass needle *n s*.

Cumming's galvanascope.

a b c, d e f, brass wires inserted in the galvanascope, and carrying the sliding wires *b g*, and *e h*, *i k*, *l m*, the neutralizing magnets attached to the wires *b g*, and *e h*; the purpose of which is to diminish or to destroy the terrestrial directive power on the needle.

o p, *q r*, a brass wire inserted in the galvanascope at *o*, carrying a small magnet, moveable round *q r*, and employed for the nicer adjustments of the needle.

The galvanascope is placed east and west; the compass needle is then brought nearly into the plane of the spiral by the large magnets *i k*, *l m*, and the adjustment is completed by the small magnet *t v*.

This being understood, the wires on which the experiments are to be made, are inserted in the tubes A, B, and the effect is immediately shown, and may be measured by the deviation of the needle.

60. A different form of this instrument has been lately described in the *Philosophical Magazine* for December, 1823, by an ingenious artist, James Marsh. It is as follows:

Fig. 24 Marsh's galvanascope.

AB, CD, (fig. 24) are two wooden supports or pillars, through which pass brass wires, having each at its extremity a small brass cup; to the other extremity of each is attached, by good contact, the square helix cage shown in the figure; on the top of the prop E is a fine point, carrying a very light and delicate compass needle, with a card below; F G is a stand for holding the bar of bismuth, antimony, or other metal; R S, and *n m*, *n′ m′*, are wires of a different metal, soldered or bound round at the ends R and S. The set-screw at *s*, is for adjusting to any height. The brass cups being now rubbed with a little nitrate of mercury, and pure mercury being poured into them, the contact is made or broken at pleasure, by placing the wires in, or throwing them out of the cups; and the effect thus produced is shown in the most sensible manner by the needle within the cage; which, in very delicate cases, may be neutralized by the small magnets *n s*, *n s* in the foot below, when the instrument is placed east and west, or by inserting them in holes, for the purpose, in the props A B, C D, as seen at *p* and *q*, when it is in the meridian. Then by applying the lamp at R, then at S, changing the bars and wires, and the size of the latter, &c., all the variety of experiments connected with this inquiry, may be readily performed.

Continuation of Cumming's experiments.

61. Having thus explained the means adopted to carry the experiments into effect, we shall proceed to describe them more at length. It was stated, that all the different metals possessed the property in question, but in different degrees, and with opposite characters. If, for instance, a bar of bismuth, having copper wires at each end, be heated at one extremity, on placing the wires in the mercurial cups of the galvanascope, the heated end produces a deviation of the compass needle, in the same direction as the wire from the silver disc in the common galvanic circuit; with antimony it is the reverse. These metals may therefore so far be considered as positive and negative to each other. On examining the other metals with *copper wires*, Professor Cumming found, that they might be distinguished into two classes, the heated end of the one, and the cooler end of the other, exhibiting the silver or positive electricity; but there were some singular modifications when other wires were employed which engaged much of the author's attention, and will, we have no doubt, excite great interest in the minds of other experimenters in this novel and instructive branch of philosophy. In detailing these modifications it will be best to use the author's own words.

62. "If the bar be of copper, the deviation becomes negative, or positive, accordingly as the wires are platina or silver; or if the extremities be considered as positive and negative with the one, they are negative and positive with the other. The same effect was produced with a bar of zinc, and *zinc* or copper wires, and with silver, platina, and palladium, as the wires were silver or platina. In these instances it seems remarkable, not only that the bar appeared to change its electrical station with different wires, but that electricity, or rather electro-magnetism, should be exhibited when the bar and wire were of the *same* metal. In the first case, it might be supposed, that the electricity was excited by the contact of dissimilar metals; (that is, dissimilar as to their galvanic relation,) as, in the galvanic circuit, copper is positive to zinc, but negative to silver. But this hypothesis is applicable to cases of the second description. If the effect depended on the contact of dissimilar metals, it would be greatest between those which are opposed in the galvanic circuit, and would cease when the bar and wire were of the same substance.

" On making the trial with a bar of zinc and silver wires, the deviation was not greater than that by the same bar and wires of zinc. Again, platina and silver are both positive with reference to copper, yet the deviations were opposite; and silver and copper bars acted strongly with silver and copper wires respectively. As in these instances, to prevent ambiguity, the wires were not soldered, but rivetted to the bars. I cannot but conclude, that the hypothesis of electricity being excited by the contact of dissimilar metals, is, whatever plausibility it may possess in other circumstances, inapplicable to the case of its developement by heat.

63. "The following experiment is, I think, decisive. Two wires, each composed, the one half of platina, the other of silver, soldered together in the middle, were rivetted into a bar of brass. When the silver ends were connected with the brass, the deviation was positive; on reversing each wire, and therefore connecting the platina and brass, it was negative, still retaining the platina contact; but shortening the platina wire to about half an inch, the deviation again became positive. In every case the brass was in contact with a metal highly positive with respect to itself, yet the deviations in the two last were in opposite directions, though the contact of brass and platina was the same in both.

64. "If these experiments be referred to the hypothesis, which accounts for electrical excitation by the oxidation of the metals, they seem equally adverse to it. Not to repeat the instances of its production, where the heated bar and the wires were of the same metal, and in consequence similarly, if at all, oxidated; it can scarcely be imagined, that an elevation of temperature of not more than two or three degrees, should cause a difference of oxidation; and it is to be remarked, that the effect is produced, whether the temperature be elevated or depressed. On placing one end of a bar of bismuth in a freezing mixture, or even by allowing a few drops of ether to evaporate from its surface, there was produced a considerable deviation on the needle of the galvanascope; that extremity which remained at the temperature of the room, acting as the heated end of the bar in the other instances.

"Having ascertained that in *all* the perfect conductors of electricty, electro-magnetism may be excited by the unequal distribution of heat, my next endeavour was to determine the direction in which this peculiar influence is exerted, and the mode of its

Fig. 25. propagation. If a bar of antimony, A B (fig. 25,) having its ends connected by copper wire, A a' b B, be heated at one extremity, and presented to the compass, the deviation, in every part both of the bar and the wire, is of the same nature, and therefore the current of electricity (if there be such a current) is throughout in the same direction. The effect is similar, whatever metal be employed; but, as will be seen by reference to the first of the following tables, the direction of the current in some is opposite to that in others. If two bars of the same or of similar metals (that is similar, as to their developement of electro-magnetism by heat) equal in power, be connected at their heated extremities; or, which is the same thing, if a single bar be heated at the middle no effect is produced, the equal and opposite currents counteracting each other: if under the same circumstances, the metals are dissimilar, the effect is that arising from the joint action of their conspiring currents. In some respects this arrangement is analogous to that of the galvanic circuit; heat in one case acting the part of an acid in the other; but there is one material difference between them. In the first, the metallic circuit is complete, and the current is, as has been already observed, in the same direction throughout every part of it. In the second, the circuit is interrupted, and the current through the acid is opposite to that through the wire, (fig. 26, 27.)

Ther
Elect
Magnet

Fig. 26

65. "If the bar of antimony A B above-mentioned be broken unequally into two parts, $a\,b$, $c\,d$, (fig. 28,) and these be connected by a copper wire, on heating one part and cooling the other regularly throughout, no effect is produced, however short the interval may be between them. If the parts $a\,b$, $c\,d$ be (fig. 28,) again soldered together, with a thin plate of copper interposed, they no longer act as one, but are two distinct bars. When heat is applied at the extremity n, the deviation is, as usual, negative; at e the same; but if at b, the deviation is positive, the extremity a becoming the cooler end, and the part $c\,d$ merely conducting the electricity; but as the bar cools, $a\,b$, and c the extremity of the other part, gradually assume the same temperature, and consequently the bars act negatively as at first. It appears then, that when the bar was entire, the heat was not merely conducted from one extremity to the other, but by some means modified in its progress; and that, for the production of this species of electricity, there is required the juxtaposition of two particles of the same metal at different temperatures. If, therefore, a cylindrical bar, unequally heated, be supposed to be divided into an indefinite number of circular laminæ, each will act, as a layer of hot particles upon the laminæ on one side, and of cold upon that on the other, and the total effect of the bar will arise from the aggregate action of these laminæ. Fig. 28.

"By soldering wires to a long rod of bismuth, (fig. 29,) the parts of which were alternately hot and cold, it was found that the action of the whole exceeded that of any two portions taken separately, and as the only condition appears to be, that there should exist a difference of temperature between two adjoining particles, it may be inferred, that if it were possible to increase these divisions *sine limite*, each bar would act as an assemblage of an indefinite number of small plates; as the common magnet may be conceived to be composed (if the expression may be allowed) of an indefinite number of atomic magnets." Fig. 29.

Method
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66. The highly ingenious idea advanced above, relative to the juxtaposition of two particles of the same metal at different temperatures, being an essential, if not the only condition requisite for the production of this species of electricity, led the author subsequently to a result by no means inferior in importance to any of the new and interesting facts that have been yet developed in this new branch of physics. "It occurred to me," says Professor Cumming, in an Appendix to his *Memoirs*, "that as the juxtaposition of two particles of the same metal, at different temperatures, was the sole condition requisite for eliciting electro-magnetism, it might be exhibited by the minutest metallic specimens. Portions of bismuth and antimony, each weighing one grain, were therefore placed on a silver disc, connected with the galvanascope. On touching the upper surface of each separately with one end of a heated silver wire, the other extremity of which was placed in the other cup of the galvanascope, the needle deviated through 90° positive, and negative respectively." By this method the author was enabled to examine the compound ore of iridium and osmium, of which

the largest specimen did not exceed $\frac{1}{10}$ths of a grain, and to verify in a few minutes results for which the laborious process of casting bars of different metals had been previously requisite.

Thermo Electric-Magnetism

The following are the tabulated results obtained by Professor Cumming, exhibiting the thermo electric relation of different substances.

67. *Table I.—A list of substances heated at one extremity in contact with copper wires, the wires being small in comparison with the substances examined, excepting in the cases marked.**

Positive.	Negative.
Bismuth.	Antimony.
Mercury.	Iridium and Osmium.*
Nickel.	Rhodium.
Platina.	Gold.
Palladium.	Zinc.
Cobalt.	Iron.
Silver.	Arsenic.
Tin.	1 Bismuth + 1 zinc.
Lead.	1 Bismuth + 1 tin.
Copper.	1 Zinc + 1 tin.
Brass.	1 Zinc + 1 lead.
1 Nickel + 1 iron.*	4 Zinc + 1 antimony.
1 Tin + ¼ antimony.	1 Nickel + 1 palladium.*
Solder (common.)	1 Nickel + 2 platina.*
Pewter.	Printers' type.
Galena.	Fusible metal.
	1 Ditto + 1 arsenic.
	†Zinc + tin + copper.‡
	Sulphuret of antimony.
	Plumbago.
	Charcoal.

* None of the specimens marked thus * weighed more than half a grain.

† The specimen marked ‡ is a magnetic compound, capable of polarity; it is composed of copper two atoms, zinc and tin, each one atom.

68. *Table II.—Containing a comparative series of electro-magnetics by heat.*

	Bismuth.	Nickel.	Platina.	Palladium.	Silver.	Tin.	Lead.	Brass.	Copper.	Gold.	Zinc.	Plumbago.	Iron.	Antimony.
Bismuth	0	+	+	+	+	+	+	+	+	+	+	+	+	+
Mercury			+		+				+	+	+		+	+
Nickel	−	0	+	+	+	+	+	+	+	+	+	+	+	+
Platina	−	−	0	+	+	+	+	+	+	+	+	+	+	+
Palladium	−	−	−	0	+	+	+	+	+	+	+	+	+	+
Cobalt			−		+				+	+			+	
Silver	−	−	−	−	0	+	+	+	+	+	+	+	+	+
Tin	−	−	−	−	−	0	+	+	+	+	+	+	+	+
Lead	−	−	−	−	−	−	0	+	+	+	+	+	+	+
Rhodium	−		−	−	−				−	+			+	+
Brass	−	−	−	−	−	−	−	0	+	+	+	+	+	+
Copper	−	−	−	−	−	−	−	−	0	+	+	+	+	+
Gold	−	−	−	−	−	−	−	−	−	0	+	+	+	+
Zinc	−	−	−	−	−	−	−	−	−	−	0	+	+	+
Charcoal	−	−	−						−				+	+
Plumbago	−	−	−	−	−	−	−	−	−	−	−	0	+	+
Iron	−	−	−	−	−	−	−	−	−	−	−	−	0	+
Arsenic	−	−	−	−	−	−	−	−	−	−	−		−	+
Antimony	−	−	−	−	−	−	−	−	−	−	−	−	−	0

Note.—The specimen of silver was afterwards found to be not pure; the proper place for this metal is immediately above zinc. (See *Annals of Philosophy*, N. S. No. 35.)

The above table will be found highly useful in forming any experimental thermo electric combination.

Electro-Magnetism.

69. In some subsequent experiments, Professor Cumming detected a very curious anomaly when iron wire was employed, and the heat produced by a spirit lamp; namely, that the deviation, in some cases, gradually attained a maximum, then returned through zero, and at a red heat assumed an opposite direction; an effect by no means the less interesting, that from the experiments detailed in sec. vi. of our treatise of MAGNETISM, it is shown that the magnetic power of simple iron changes its character when the metal attains this degree of temperature. The results alluded to above, are contained in the following table:

Curious anomalies noticed by Professor Cumming.

		Positive.		Negative.
Iron with silver,	deviation	10°	at a red heat	8°
	copper	13		7
	gold	7		4
	brass	17		3
	zinc	7	melting zinc	3

Similar effects were not observed when iron was used with platina or lead; and it was not noticed in any case, if iron were not one of the metals employed, but some other anomalies, not much less interesting, were noticed, as follows; viz. that when the heat was produced by dipping wires not previously connected in boiling mercury, the deviation in the *first instance* was found to depend upon which of the two wires was first immersed. Thus,

Copper with gold	copper last, negative, then slightly positive. gold last, positive.
silver	copper last, negative. silver last, positive, then negative.
zinc	copper last, negative. zinc last, positive, then negative.
brass	copper last, negative slightly, then positive. brass last, positive.
plumbago	copper last, negative. plumbago last, positive, then negative.

Similar results were obtained with zinc, iron, plumbago, gold, and brass, and other combinations.

These peculiarities, and the other interesting facts, which have been noticed above, seem to offer some of the best criterions hitherto known for tracing to its source the principle of this curious science. A number of other important facts relative to these inquiries, may be seen in the Memoir from which the above abstract has been made, published in the *Transactions of the Cambridge Philosophical Society* for 1823.

§ IV. *On the theory of Electro-Magnetism, and its application to the illustration of a course of Electro-Magnetic experiments.*

Sketch of the different theories of electro-magnetism.

70. At present we have only very slightly alluded to the theoretical principles of this science, it will, however, be proper now to give some particulars relative to the theories that have been advanced, for explaining and generalizing the numerous facts elicited by the several experimenters whose names have been recorded.

Theory Elect Magnet

Oersted theory.

In this part of the subject Professor Oersted, to whom the science itself owes its birth, stands first in the order of date; the theory, in his mind, having preceded and led the way to the discovery. It appears that, so far back as the year 1806, or 1807, when this philosopher began to examine into the nature of electricity, he conceived the idea that the propagation of electricity consisted (to use his own words) in a continual destruction and renewal of equilibrium, and thus possessed great activity, which could only be explained by considering it as an uniform current: he then regarded the transmission of electricity as an electric conflict, and his researches into the nature of heat, produced by electrical discharges, led him to the conclusion that the two opposite electrical forces, which pervade a body heated by their effects, are so blended as to escape all observation, without, however, having acquired perfect equilibrium; so that it was probable they might still exhibit great activity, although under a form of action differing entirely from that which may be properly termed electrical. It must be acknowledged, that it is difficult from the above statement to comprehend the views of the author, and we are by no means certain that we properly understand them; but he, at all events, was led, by some considerations of this kind, to suspect, as light and heat were both developed in an electrical discharge, that probably so also was magnetism; and in another place the author says, "it must then be determined whether electricity in its most latent state, has any action on the magnet as such." It is singular that, after entertaining such an idea, its truth should have remained so long a mere matter of speculation, and that it should not till the month of July, 1820, have been satisfactorily exhibited by experiment. This being, however, at length effected, some more distinct views of the mode of action developed themselves to the author, and which are stated by him as follows: "When opposite electrical powers meet under circumstances which offer resistance, they are subjected to a new form of action, and in this state they act upon the magnetic needle in such a manner, that positive electricity repels the south, and attracts the north pole of the compass; and negative electricity repels the north, and attracts the south pole; but the direction followed by the electrical powers is not in this state a right line, but a spiral one turning from the left hand to the right." As far as we can comprehend Mr. Oersted's ideas as above expressed, it is, that when the opposite electricities meet in their progress through the conducting wire, the positive electricity is turned out of its natural rectilinear course, and is made to perform a spiral motion along the wire in one direction, while the negative electricity, in like manner, performs a similar spiral motion in an opposite course, and that in this state the action exerted by these currents is no longer electrical but magnetic.

The author does not state, but we conceive that he means, that the spires of this spiral are indefinitely near to each other, and, therefore, that the magnetic action is thus exhibited, either exactly, or very nearly, in a tangential direction to the conducting wire. Indeed, as the spiral motion in this form differs very little from a circular current about the wire, the author assumes the circular motion in all his subsequent illustrations. We may, therefore, it is presumed, state, in concise terms, that Mr.

Oersted's idea of electro-magnetic action is, that the conflict of the two electricities produces in these fluids a new mode of action, which is exhibited by its action on the magnetic needle in circular currents at right angles to the direction of the conducting wire. By means of this principle the author illustrates not only the action of a galvanic wire on the magnet, but the action of one galvanic wire on another; the discovery of which fact is due to M. Ampere.

mpere's
eory.

71. Let us now give some idea of what we conceive to be M. Ampere's theory of these actions. This philosopher seems to deny, in *toto*, the existence of magnetic fluids, or forces, otherwise than as they arise from certain electrical actions.

In his repetition of Mr. Oersted's experiments, he discovered that two conducting wires of the same, or of different galvanic batteries, acted on each according to certain principles; viz. that when the wires were parallel to each other, and the currents in each passing in the same direction, they were mutually attracted; and when the currents were passing in opposite directions they were mutually repelled. And with this fact he ventured upon the bold assumption, that what we have hitherto been accustomed to consider as magnetic fluids, or forces, in a natural or artificial magnet, consist merely of electric currents always revolving about every particle of such a body in planes perpendicular to its axis, so that the attraction or repulsion that takes place between the opposite poles of two magnets, is merely the attraction of these electric currents; and in the same way the direction, which a magnetic needle assumes when under the influence of a galvanic wire, proceeds from the attraction between the wire and the parallel currents in the magnet when these correspond in direction, or from the repulsion between them when the currents are in opposite directions. And, in like manner, the direction which a needle assumes from the terrestrial action, is not, as has been hitherto assumed, due to magnetic poles in particular situations in the earth, but to the attraction of electric currents circulating about the earth in circles nearly parallel to the equator.

Compared
with Oer-
sted's.

72. This theory serves to generalize a great number of facts; viz. *first*, the action of electrical currents on each other, as they are exhibited by freely suspended conducting wires; *secondly*, the action exhibited between a galvanic wire and a magnet; *thirdly*, the action of magnets on each other; and, *fourthly*, the principles of terrestrial magnetic action; and therefore, whether it be or be not a true exhibition of the actual mode of action, it possesses great advantages as an hypothesis, by its generalizing so many facts, and is highly creditable to the genius and talents of the author. That it is not actually a correct exhibition of the *modus operandi*, appears probable, because, in the first place, we can see no reason why a current of electricity in motion should possess a power which it does not exhibit when at rest; considering it as M. Ampere does, purely as an electrical property, and not as a power impressed upon it in consequence of the opposition or conflict of two electricities on each other. In this respect we think that Mr. Oersted's ideas approach perhaps nearer to the truth. It is, moreover, an immense demand upon the reader to request him to admit an infinitude of infinitely small electric currents perpetually circulating within the solid mass of a magnet or steel bar. It is, for instance, much easier to imagine that the conflict of the electrical fluids in the conducting wires, should give rise to magnetic currents in planes perpendicular to the axis of the wire, and that these should act upon the magnetic particles in a bar of steel, whose direction is parallel to the axis of the bar, than to suppose the electric transmission to be made in right lines, and that these currents in this state act upon the corresponding supposititious circular currents in the magnets; and either hypothesis, if we are not much mistaken, will lead to the same results, at least as far as they serve to illustrate the electro-magnetic action. It is, for instance, obvious, that whether we consider currents of magnetism perpendicular to the axis of the wire attracting the lines of magnetic particles whose directions are parallel to the axis of the magnet, or whether we conceive currents of electricity revolving in planes perpendicular to the axis of a magnet, attracting the line of electric particles parallel to the axis of the wire, the result in both cases will be the same; namely, to place the axis of the electric and magnetic particles at right angles to each other, and to the line which may be conceived to join them; which is precisely the principle that we have seen, (art. 43,) Mr. Barlow has laid down in order to deduce from it the mathematical laws of electro-magnetism.

73. To see the agreement of the two hypotheses a little more distinctly, let the reader conceive a galvanic wire to be every where encompassed by magnetic currents perpendicular to its direction at any point, and imagine these attracting the magnetic particles in a magnet arranged, according to the common hypothesis, parallel to the axis of the magnet; then it is obvious, if a magnetic particle thus situated were free, it would arrange itself parallel to the magnetic currents in the wire, and therefore place itself at right angles to the direction of the wire and to the line joining the magnetic particle, and the general centre of action of the wire; that is, the magnetic and electrical particles would be placed at right angles to each other.

Let us now, with M. Ampere, suppose the direction of the electricity to correspond with that of the wire and the magnetic particles, (which we will suppose, for the present, still existing in the magnet,) to be surrounded by electrical equators perpendicular to their axis, and let us conceive the current in the wire to attract or repel these electric equators, then, again, it is obvious that the action between the wire and the equators of any magnetic particle will be to bring these parallel to each other, and consequently to place the particles of the two fluids perpendicularly to each other, exactly as in Mr. Oersted's hypothesis. It is true that M. Ampere admits of no magnetic particles, but attributes every magnetic phenomena to these equators only; this, however, does not affect the case, as we have put it; the existence of the particle being merely admitted for the sake of the idea of direction.

Both con-
sistent with
Mr. Bar-
low's hypo-
thesis.

So that whether we employ the hypothesis of Mr. Oersted, or that of M. Ampere, we still arrive at that result which Mr. Barlow has made the foundation of his investigation of the mathematical laws of electro-magnetic action: viz. "That every particle of the galvanic or electric fluid in the conducting wire, acts on every particle of the magnetic fluid or a magnetised needle, with a force varying inversely as the square of the distance; but that the action of the particles of the fluid in the wire is neither to attract nor to repel either poles of a magnetic particle, but a tangential force which has a tendency to place the poles of either fluid at right angles to those of the other."

And as our object in this place is not to reduce the principles of magnetism to those of electricity, but merely to illustrate the several electro-magnetic phenomena, and as the latter hypothesis is by far the most simple idea that can be formed of this action, we shall for the present, as the safest plan, not stop to inquire into the mechanical means by which such a power is brought into action, but simply conceive it to exist, and thence endeavour to explain the various facts and reciprocal actions which have been observed to take place between a galvanic wire and a magnet.

Before we commence, therefore, our course of experiments, it is desirable that the reader endeavours to make himself familiar with the idea of his coinciding in position with any part of the conducting wire, and then to retain in his mind this formula: that when his head is towards the positive pole of the battery, and his face to the magnet, the north pole of the latter, or of a single particle, will be urged to his left hand, and the south pole to his right hand; and the contrary with the contrary position.

This being properly comprehended, the explanation of the several phenomena exhibited in the following course of experiments, will be found exceedingly simple and satisfactory.

Course of Electro-Magnetic experiments.

Experiment I.

74. *To illustrate the nature of the tangential force assumed in the theory.*

Fig. 30. Tangential force illustrated.

The reader conceiving himself to be making experiments on the table, fig. 11, plate I., let *w* fig. 30, be supposed to represent a section of the wire proceeding from the zinc or positive end of the battery downwards to the copper; and let *n s*, *n s*, &c. represent a magnetic needle in various positions about the wire. Let the effect of the terrestrial power on the needle be neutralized, by opposing to the needle a strong magnet at a proper distance, whereby it retains its magnetic power, but possesses no direction. If now the wires be connected with the poles of the battery, the needle will, wherever it is posited, take up one of the directions shown in the figure; that is, it will place itself directly at right angles to the wire, and to the line joining the centres of the needle and wire, or in a tangential direction to the wire at the point where the latter line meets its circumference.

If the upper part of the wire, as we have supposed, be connected with the zinc end of the battery, then the needle will assume the direction shown in the figure; that is, such that a person conceiving himself coinciding with the wire, and his head upwards or towards the zinc, and looking towards the needle, will find the north end of the latter on his left hand, and the south on his right; but if, on the contrary, the upper part of the wire be connected with the copper end of the battery, then also the needle will assume a similar tangential direction; but the north end will now be carried to the right hand, and the south to the left; that is, the direction of the needle will be reversed.

In like manner, if instead of the needle turning on a pivot, as supposed above, we conceive it turning on an axis like a dipping needle, and bring it against the upper or lower wire of the rectangle, (fig. 11,) then, also, the same tangential position will be observed, and the same principle obtained with regard to direction, as in the other case, the reader still assuming his position as coinciding with that of the conducting wire.

In our hypothesis we assume this as a fundamental principle of action, and therefore make no attempt to reduce it to mechanical principles; but M. Ampere, by going one step farther back, illustrates or accounts for this phenomenon by assuming that every particle of the needle, taken in the direction of its length, is encompassed by an electric current revolving in planes perpendicular to the axis of the needle, and which currents are attracted by the current in the wire, and brought parallel to it, and which consequently tends to place the needle at right angles to the wire, as shown in the figure.

Second method Fig. 31.

Another method of exhibiting this effect is shown in fig. 31, where A B represents a horizontal section of a wooden vessel having a hole in its bottom, which slips tightly over the vertical wire of the rectangle, (fig. 11,) so as to hold a quantity of water, and *n s* is a magnetic needle stuck through a bit of cork so as to keep it afloat; the wires being then connected with the battery, the needle will first arrange itself in the tangential direction *s n*, and then gently approach the wire coming in contact with it in its middle point. This approach M. Ampere would explain by the attraction between the electric current in the wire, and the currents in the needle perpendicular to its axis. According to our principle of illustration, the extremity *n* of the needle is urged in the direction *n m*, and the extremity *s* in the direction *s r*, each perpendicular to the radii *s* W, *n* W, and which, of course, will urge the needle towards the wire in the manner exhibited by the experiment.

Third method Fig. 32.

Another interesting form of this experiment is as follows: Let Z *a b c d* C, fig. 32, represent a galvanic wire of the form there shown, and A B a vessel of water, *n s* is a magnet stuck through a piece of cork, having one of its poles, as for example, the south, as much below the surface of the water as possible, and the other just above it. Let this be set afloat in the basin, and make the contact with the battery, and immediately the magnet will be affected and advanced *towards* the opening between the two branches of the wire, having its motion accelerated as it gets nearer, and when directly between them it will be urged with still greater force *from* the wire on the other side, and be carried to a distance where the influence of the wire ceases.

There is no question, we believe, that M. Ampere's theory is fully competent to the explanation of this experiment, but it is not immediately obvious; whereas, according to the principles advanced above, we see that the wire being ascending on one side, and descending on the other, the action of both branches conspire to give to the pole *n*, the only one exposed to the action of the wire, a motion in the same direction, and that this action will be greatest when the pole is between the two branches. With the combination shown in the figure, the motion is to the left hand of a person standing in the wire *c d*; but by

lectro-
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changing the contact, or by inverting the magnet, the motion will be reversed.

If the needle be made to float horizontally on the surface, as in the last experiment, then it will not pass through the branches of the wire, but remain in a central position with its middle point exactly in the plane of the two legs, as ought obviously to be the case, both wires acting with opposite forces on the two poles.

EXPERIMENT II.

75. *To magnetise steel bars with the galvanic battery.*

mag-
tise steel
s.

Take a piece of steel wire, as for example a sewing needle, and dip its ends first into steel or iron filings, in order to ascertain that it has no magnetism already in it, which will be the case if the particles of iron do not adhere to it; if they do, another needle must be tried, till we find one free from every species of magnetic action; this being done, connect the ends of the battery by the conducting wire C Z, and place the needle N S across it, (fig. 33,) and it will be found in a very short time to have acquired the magnetic property; for on immersing its extremities again in the filings they will be found to adhere to it, in the same manner as to a needle magnetised in the usual way.

g. 33.

This very interesting experiment is strictly conformable to our hypothesis; for, according to this, the action of the galvanic particles in the wire being tangential, will act upon the latent magnetic particles in the needle, in the direction of its length, and cause a displacement of them, precisely in the same manner as would be done by a magnet; and also, as in that case, the cohesive power of the steel preventing the return of the fluids to their natural state, the needle will remain magnetic.

If the needle be made a part of the galvanic circuit, or if it be placed lengthwise of the wire, no perceptible permanent magnetic power will be developed, which is also consistent with the hypothesis; because in this case, the action of the wire will be transverse of the needle, which is the least favourable direction for the developement of the magnetic power; the tendency of the action being to place the poles transversely instead of lengthwise.

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he needle.

In order to ascertain the polarity given to the needle in this experiment; let the needle and wire be placed as in the last experiment, (see foregoing figure,) that is, the needle being above the wire, and Z denoting the zinc end of the battery of two plates only, and it will be found that the extremity N will attract the south end of a compass needle, and the extremity S the north end; in short, that the north poles of the latent magnetic particles have been carried towards the left hand, and the south towards the right hand, agreeably to the principles indicated in art. 43.

Let now the needle be placed under the wire, instead of being placed over it, and in other respects the process described in the last example repeated, and it will be found that the polarity of the needle will be exactly the reverse of that in the last experiment, which ought to be the case according to the principle of the above article; because by this the north polarity is always carried to the left hand of the observer, who conceives himself to form the galvanic circuit, his head being towards the zinc end, and his face towards the magnet; for thus his position being now the reverse of what it was in the preceding experiment, the polarity ought to be the reverse also.

Course of
Experiments.

EXPERIMENT III.

76. *To show the effect produced by a galvanic wire on steel or iron filings.*

The effect
on steel
and iron
filings.

This experiment is performed by strewing a quantity of iron dust or filings on a table, and bringing the connecting wire near to them, when the filings will immediately be affected by the action of the wire, some few flying towards it and adhering to it as to a magnet; and if the wire be brought into actual contact with them, a very considerable quantity may be taken up by it, exactly the same as at the extremity of a bar magnet; but the moment the contact is broken the filings fall.

In order to produce the best effect in this experiment, the wire intended to be operated upon should be smaller than the conducting part of the circuit. This latter, in all cases, is the better for being stout, at least $\frac{3}{16}$ of an inch in diameter; but in this, as in several other experiments, it is best to have the extremities of the wires terminated by a much smaller wire, wound round the former as a spiral, or by simple contact, for by this means the transmission being made through a smaller space, the intensity of action is proportionally increased.

This experiment, as we have already stated, is due to M. Arago, and it seems at first sight somewhat at variance with our hypothesis; because we have here an appearance of actual attraction between the iron and the wire, whereas we have supposed that there is no attraction between them. A little consideration will, however, show, that instead of contradicting, this fact will serve to confirm the hypothesis in question.

Let us, for example, conceive W (fig. 34) to denote the section of our conducting wire descending vertically from the zinc end of the battery; then, the first and direct action of this wire will be to excite magnetism in any small particle of iron *n s*, according to the direction indicated by the letters in the figure, and agreeably to what has been stated in Experiment II.

Fig. 34

After which, the action of the wire will be to urge the point *n* in the line *n n′*, perpendicular to *n* W, and the point *s*, in the line *s s′*, perpendicular to *s* W; and, in consequence of the combined action of these forces, the particle *n s* ought necessarily to approach the wire in the same way as it would do by a direct attractive force. As we have already explained in Experiment I.

This experiment may be pleasingly varied by using an helix instead of a straight wire. The best form of which, in this case, is that where the wire lies all in one plane, as in fig. 35. This being connected by its two extremities with the poles of the battery, will take up an astonishing quantity of filings, which, by their reciprocal attraction towards each other, exhibit the most pleasing appearance.

Fig. 35.

EXPERIMENT IV.

77. *To magnetise a needle by placing it in a spiral conducting wire.*

Let Z C (fig. 36) represent a conducting wire bent into a spiral form, and let the needle *n s* be placed

Fig. 36.

Action of a spiral illustrated.

either naked in the spiral, or enclosed in a glass tube, or in a tube of any other matter; make the connection with the battery, and in an instant it will be found that the needle *n s* has become strongly magnetic, having its poles posited, as shown in the figure, viz. having its north end towards the zinc extremity of the battery.

This is of course precisely similar to Experiment II. the only difference being, that by means of the spiral form given to the wire, the action upon the needle is repeated as many times as there are spires of the wire covered by it; the power excited is therefore proportionally stronger, and the magnetism more quickly communicated. The explanation of the effect produced is exactly the same as in that experiment. If the direction of the contact be changed by supposing Z to communicate with the copper side of the battery, the effect will be in all respects the same, except that the polarity of the needle will be reversed. The end towards Z, in this case, becoming the south instead of the north pole.

Fig. 37.

Or, if a spiral, having its spires turned the contrary way, as shown in fig. 37, be used, and Z be supposed to communicate with the zinc side of the battery, the polarity will also be the reverse of that in the first case; viz. the poles will have the direction marked in the figure; and if here again the contact be changed by connecting Z with the copper side, the poles will be once more inverted, and have the same direction as at first. These facts, as we have stated above, are explained exactly in the same manner as those for the single wire.

In performing this experiment, Mr. Barlow employed a glass tube about five inches in length and half an inch in diameter; and it was observed, when the needle was placed in it, so that one half of it projected beyond the end, that the moment the plates reached the acid, (the spiral being previously connected with the poles of the battery,) the needle was drawn instantly to the middle of the tube, and while the contact was continued, it was held suspended in the centre of the tube when the latter was held vertically; the suspending power of the spiral exceeding that of gravity.

This effect is very curious, because the needle here remains suspended in the open space, directly in the axis of the tube, and not attached to either side as in the usual cases of suspension by attraction.

Experiment V.

78. *To imitate a bar magnet by a galvanic wire.*

Bar magnet imitated with a galvanic wire.

Let a piece of copper or brass wire be wound round any small cylinder, so as to give it a regular spiral form as in the last experiment; and when completed, remove the cylinder and pass each wire down from its respective end to the middle, and then let each be turned through without touching the wire, which may be readily done if the wire possesses sufficient stiffness. Let, then, the ends Z and C be carried off to the poles of the battery, and the connection established. This done it will be found that one of the extremities of the spiral, as N, will be a decided and strong north pole, and the other extremity a south pole possessing all the properties of a common magnet, as far as regards its magnetic action on a needle; but it has certain peculiarities, which will be noticed as we proceed. It is unnecessary to add, that by changing the contact the poles will be inverted.

This experiment, which is due to M. Ampere is highly favourable to his theory, which reduces all magnetic phenomena to currents of electricity; the effect produced, however, is equally consistent with our hypothesis; for at the extremities of the spiral we have the sum of all the effects of the tangential actions of the wire in one direction, while in any intermediate part of its length, the spiral on one side, and on the other are acting in opposite ways, and are completely neutralized in the centre. See fig. 38.

Fig. 38.

Experiment VI.

79. *To examine the effect of a spiral conducting wire on a floating magnetised needle.*

Effect o spiral w on a flo ing nee Fig. 39.

Let a wire be wound about a glass tube of about half or three quarters of an inch diameter, and hang it within a basin of water, as shown in fig. 39, so that the surface of the water rises to about the axis of the bore; then having pierced a small piece of cork with a needle previously magnetised, so as just to preserve it from sinking when immersed in the basin, make the connection with the battery. The needle will instantly be agitated, and will soon arrange itself in front of the spiral in a direction parallel to its axis, and then suddenly dart into the interior of the tube with a force nearly sufficient to carry it to the other extremity; it then returns again towards the other end, and at length becomes stationary in the middle of the axis, arranging itself exactly parallel to it.

If the spirals have the direction shown in the figure, and Z communicates with the zinc side, the needle, if placed near the extremity of the tube A, will enter with its south end; if placed near the other extremity, it will enter with its north end; but if the direction of the spiral be changed, the needle will enter in both cases the reverse way, as it will also if the direction of the spires remain the same, but the contact be changed. This experiment will succeed equally well if the tube be placed upright in the water, the needle will then dive like a fish, and remain below till the contact is broken.

This entertaining and instructive experiment is due to Mr. Faraday; the explanation of it by our hypothesis is obvious, for the north pole of the particles of the needle being carried to the left of an observer conceiving himself coinciding with the direction of the wire, and with his head towards Z, all the effects ought to take place precisely as above stated. M. Ampere, as we have seen, had assimilated a spiral wire of this kind with an actual magnet, and Mr. Faraday instituted the above experiment to show that there was not that identity which had been assumed; for by suspending a hollow cylindrical magnet in the same way, the needle was always attracted to the nearest extremity of its edge, and indicated no tendency to enter the tube.

To this, however, M. Ampere has replied, that if we consider the electric currents, which give action to a magnet, to circulate about every particle, then it ought to follow that a needle cannot enter the bore of a hollow magnet; because even in this form we are still outside of the revolving currents, so that a magnet, according to M. Ampere, can only be strictly imitated, but by combining in one an infinite number lectro- gnetism.

of infinitely small spirals of the kind here represented.

EXPERIMENT VII.

80. *To exhibit the terrestrial directive quality of a galvanic wire.*

rrestrial ective wer on a vanic re illus- ted.

It was not long after the first experiments of Mr. Oersted, that the question naturally suggested itself, "Has the galvanic wire a directive, as well as a general, magnetic power?" This question was soon answered in the affirmative by M. Ampere, who made use of the following ingenious construction:

g. 40.

A B, fig. 40, represents a piece of wood fixed to any convenient support, through which pass the two wires G, E, and where they remain fixed. At their upper and lower extremities are soldered the small metal cups *a*, *b*, *c*, *d*. D H I K, &c. is a part of the conducting wire, bent into the form shown in the figure, having small steel points soldered upon it at *c* and *d*. These points are inserted into the cups *c*, *d*, the upper one only resting on the base of its cup, the other being merely brought into contact with *d*, by a little quicksilver placed in it for that purpose, by which means the rectangle has a great freedom of motion given to it, the only solid contact being on the point *c*. Mercury is also poured into the other cups for the sake of a more perfect and certain communication than that afforded by the mere juxtaposition of the wires.

The apparatus being thus prepared, the two wires proceeding from the copper and zinc sides of the battery, are inserted into the cups *a*, *b*, and thus the connection is established; first, by means of the wire G with the cup *c*, thence by means of the contact of the point with the cup and mercury, it is carried forward from *c*, through the rectangle, to the cup *d*, whence it proceeds to the cup *a*.

We have already seen that of this connecting wire, the part from *c* to *d* has a perfect freedom of motion upon the point at *c*, and will therefore obey any exciting force. This force, in the experiment in question, is the magnetic influence of the earth, and in consequence of which the rectangle, immediately the contact is made, places its plane perpendicularly to the plane of the magnetic meridian, and to which position it will always return after a few vibrations, if it be drawn out of it by the hand, or otherwise.

This arrangement of the moveable conductor is perfectly consistent with our hypothesis, as is obvious without any further illustration than what has been given in the several preceding experiments; the magnetic poles of the earth now acting as those of an artificial magnet.

Fig. 41.

A differently formed wire, and a more simple mode of suspension, is shown in fig 41. Here a brass or copper wire A C, rests at its bent end A, in a cup containing a little mercury, and is very moveable in azimuth round this point. The other end passes through the centre of a circular piece of pasteboard, and then forms spiral turnings in the plane of this circular piece. The wire is attached by thread or silk to the pasteboard disc, and at the point B it turns and descends till its extremity reaches the quicksilver in the cup D. The communication being now made at A and D with the battery, the spiral will immediately arrange itself, as in the last case, in a plane perpendicular to the magnetic meridian. This experiment is originally due to M. Ampere, and is one of great importance, as connecting the terrestrial magnetic powers with galvanism.

Course of Experiments.

Fig. 42.

A needle upon a different and still better construction, also due to M. Ampere, is shown in fig. 42

81. *The same otherwise.*

The directive quality of the galvanic wire has been since exhibited in a variety of ways, much more simple than that above described, of which we shall only state the following:

M. de la Rive's apparatus.

M. de la Rive's apparatus.—This consists of a small galvanic combination attached to a cork; the plate of zinc is nearly half an inch wide, and extends about one and a half or two inches below its cork, its upper end passing through the same; the slip of copper is of equal width to the zinc, but passes round it, being thus opposed to both its surfaces, as in Dr. Wollaston's construction; its upper end also appears through the cork. A piece of copper wire, covered with silk thread, is coiled five or six times, and tied together so as to form a ring about an inch in diameter, and the ends of the wire are connected, by solder, one with the zinc, and the other with the copper slip above the cork. See fig. 43.

Fig. 43.

When this small apparatus is placed in water, slightly acidulated with sulphuric or nitric acid, the ring becomes highly magnetic, and will arrange itself in a plane perpendicular to the magnetic meridian, or it will at least indicate a tendency to take up that position, but the escape of the bubbles, arising from the decomposition of the water, prevents it from preserving a fixed direction.

Its magnetic qualities, however, are more obviously shown by bringing to it a strong magnet, such, for instance, as a cylindrical one about three quarters of an inch in diameter, and eighteen inches in length. This being applied at the distance of several inches, the ring is immediately attracted or repelled, accordingly as one or the other of the poles of the magnet is presented, or accordingly as one or the other side of the wire is opposed to the latter. When the result of the application is attraction, the cork will advance towards the extremity of the magnet, and if the latter be held horizontally, and in a line with the centre of the former, this will continue to advance till the pole of the magnet is within the ring, and then proceed with considerable velocity till it reaches the middle of the magnet, where it remains perfectly stationary. If now the magnet be withdrawn, and changed end for end, and reintroduced into the ring, the latter will go off from the magnet, turn itself round when quite free from it, again advance and settle itself as before in the centre.

This very simple apparatus, which may be made at the expense of about a shilling, throws great light upon the nature of the electro-magnetic action, and shows most satisfactorily, that, notwithstanding the intimate relation between the electro-magnetic and simple magnetic powers, they are not identical; a similar difference being observable here, as in Experiment VI. All the above facts will be found perfectly consistent with the hypothesis that has been advanced; for it will be seen, when the wire and cork are in equilibrio, as above stated, that an observer, conceiving himself situated as in art. 43, will have the north end of the magnet to his left hand, and the south to his right, at equal distances, and acting therefore with equal and opposite powers; consequently the wire itself ought to be in equilibrio, and when disturbed from it will have a tendency to regain it, and hence be subject to all the conditions of motions that have been described. This is, in fact, very similar to Experiment VI. the difference only consisting in this, that in the present case the wire is moveable and the magnet fixed, whereas in the former, the wire was fixed and the magnet free; the explanation is of course the same in both.

Fig. 44. Marsh's construction of this apparatus.

Another form of this apparatus is shown in fig. 44. Both the above apparatuses are much improved by fixing to the cork a light glass cylinder A B to contain the acid, instead of floating them in it; the apparatus may then be floated on common water, and all the facts exhibited as above described.

This appendage to the original construction is due to Mr. James Marsh, an ingenious artist at Woolwich.

Mr. Marsh has constructed a portable electro-galvanic apparatus; which within the space of little more than a cubic foot, contains not only the necessary galvanic combination, but also all the instruments necessary for repeating nearly the whole of the experiments detailed in this section. For this curious construction the inventor received thirty guineas and the silver medal of the Society for the Encouragement of Arts and Manufactures.

Fig. 45. Professor Van den Boss's apparatus.

82. *Apparatus of Prof. Van den Boss.*—Here C D, fig. 45, is a copper plate, E G a similar one of zinc, about an inch square, kept from touching each other by the interposition of some small piece of wood: both plates are attached and suspended to slender brass wires P and R. The wire P enters at P, in the hollow space formed by a case of very thin quills inserted into each other, about six or seven inches long. The end of the wire comes out of the quill at the extremity T and returns, being wound as a spiral about it to the other extremity V; it then again enters the quill and proceeds in a right line to R, where coming out it descends and is attached to the other plate. The whole is suspended in equilibrio to a piece of untwisted silk X. The plates are now dipped into dilute acid, and the whole is suspended at X, when immediately the magnetic quality of the wire becomes manifest; but, like the former instrument, it is not so sensible to the terrestrial as to the action of a strong artificial magnet, with which its extremities T and V may be attracted or repelled, according as the one or the other pole of the magnet is applied; and which ought necessarily to be the case agreeably to the explanation given in the preceding case.

Experiment VIII.

83. *To examine the inclination of a freely suspended galvanic wire as affected by the terrestrial magnetism.*

Fig. 46. Dip of the needle exhibited by means of a galvanic wire.

This is an experiment first performed by M. Ampere, in which he employs the apparatus exhibited in fig. 46, where the galvanic circuit is carried on from the extremity of the battery towards V, passes by V S, through the steel pivot *k*, placed on the metallic plate N, and thence through the rectangle A B C D; whence, passing through the tube *x y*, which serves as an axis for the machine, it is carried by means of a second steel pivot to the extremity of the battery towards R. The moment the connection was made, M. Ampere found the moveable part of this conductor in a state of vibration, which after a short time subsided; when the plane of the rectangle was found to coincide with what has been denominated the magnetic equator of a needle,—that is, with a plane perpendicular to the direction of the dipping needle.

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It will of course be understood, that the axis of the machine must in the first instance be placed very exactly at right angles to the magnetic meridian, that the whole requires to be very nicely balanced, and that a little mercury be placed on the plates M N to render the contact the more perfect.

The lozenge *z w* is made of very light wood, and being fixed on the axis serves to keep the rectangle in its proper form.

That the machine ought, according to our hypothesis, to assume this direction, is obvious from all that has been previously stated, and therefore requires no particular illustration.

Experiment IX.

84. *To exhibit the action of the terrestrial magnetism upon a galvanic wire freely suspended.*

Fig. 47 Terrest magne action freely pended galvan wire.

Let A B G D, fig. 47, represent a rectangular piece of hard wood, having two grooves *a b*, *c d*, cut in it, parallel to its length, about half an inch in depth, which are to be filled with quicksilver for the experiment. C *p*, Z *q* are wires fixed in the board and passing each into its respective groove, with cups for making the connection with the battery at Z and C. O *m* is a long piece of silk proceeding from the ceiling, or some other convenient place, and to which is tied the wire *k m n*, bent as in the figure, the points *k* and *n* being slightly immersed in the quicksilver If now the connection be made at Z and C, with the zinc and copper sides of the battery, the moveable part *k m n* of the galvanic circuit, which has a great freedom of motion, will be projected towards the extremity A B of the board; and if the contact be changed, by making the zinc connection at C and the copper at Z, the wire will be driven towards the other extremity. As no magnet is introduced in this experiment, we have a right to attribute the motion to the effect of the terrestrial magnetism, the direction of it corresponding precisely with what we ought to expect from such action. For the terrestrial magnetism of our latitude being of the same kind as that exhibited by the southern pole of a magnet, the moveable wire ought to pass from right to left in the first case, and from left to right in the second, to an observer situated as described in art. 43; viz. as forming a part of the galvanic circuit, and with his head towards the zinc end of the battery; that is to say, with the first contact the wire ought to be projected towards A B, and with the second towards D G.

To prove that the motion proceeds from this cause, let the south pole of a strong magnet be brought under the board between Z and C, and make the contact again; and the same motion will take place, but in a much stronger degree, the wire being now thrown very forcibly out of the mercury.

The effect therefore being precisely of the same character, but much more powerful in the latter case than in the former, we have a right to conclude that the cause of the motion in both cases is of a lectro-gnetism

like nature, the one proceeding from a southern polarity artificially produced, and the other from the natural magnetic action of the terrestrial sphere, as stated by Mr. Faraday, to whom we are indebted for this interesting experiment.

EXPERIMENT X.

85. *To exhibit the rotation of a magnet round a galvanic wire.*

g. 48. tation of agnet und a re.

Let A B E D, fig. 48, represent a cup of glass, wood, or any other non-conductor, and N S a small magnet, having a hole drilled at S, whereby it may be fixed by a short piece of silk S c', to the copper wire c' C, passing through the foot of the cup;* and let mercury be poured into the latter till the needle floats nearly vertical. Conceive, also, Z z' to be a part of the conducting wire, descending from the zinc side of the battery, and slightly immersed in the quicksilver. If now the contact be made at C with the copper side of the battery, the magnet N S begins to rotate about the wire Z z', passing towards the left hand of the observer, situated according to the principles of art. 49. This rotation will be greater or less, according to the power of the battery, and will continue while there is sufficient force in the latter to overcome the resistance of the quicksilver to the motion of the magnet. If the descending wire proceed from the copper side of the battery, the motion will take place in a contrary direction, that is, from left to right.

Or, if the contact remain the same, and the magnet inverted, then also the motion will be reversed; but if the contact and magnet be both reversed, the rotation will be the same as in the first instance.

This highly curious and important experiment, which is due to Mr. Faraday, of the Royal Institution, is immediately explained by our hypothesis; according to which, the extremity N of the magnet is always acted upon by two forces, one the galvanic force, which is tangential to the wire, and the other the tension of the silk S c', in the direction of the magnet. Let this latter be resolved into two forces, one vertical and the other horizontal, and we shall find the extremity N under the influence of two horizontal forces, one always central and the other tangential. The result of which must be a rotation of that point about the wire; and it will be made with the position and arrangement shown in the figure, from right to left, the observer supposing himself situated as in art. 49.

EXPERIMENT XI.

86. *To exhibit the rotation of a galvanic wire about the magnet.*

Fig. 49. Rotation of a wire round a magnet.

Let A B D E, fig. 49, be a cup or vessel of wood or glass, and N S a magnet passing tight through its foot; Z z, a conducting wire descending from the zinc side of the battery, and rendered free to move by the chain connection at g. Let mercury be poured into the vessel till the extremity of the wire is slightly immersed in it. Then the contact being made at C, (which, by means of the wire D C, communicates with the quicksilver,) the wire g z will immediately assume a rapid rotatory motion, much greater than in the former case, the resistance being very considerably diminished by the mode of suspension. The direction of the motion, according to the arrangement in the figure, being from left to right, to a person coinciding in position with the magnet. It may, however, be reversed by reversing the magnet, or by changing the contact, as in the preceding cases.

Course of Experiments.

This experiment is also due to Mr. Faraday, and its explanation is the same as in the last; for since when the magnet is free it will, as we have seen, revolve about the wire from right to left, it follows that, when the magnet is fixed and the wire free, the latter will revolve in an opposite direction, (the action and reaction between the wire and the magnet being reciprocal,) which is still however towards the left of a person supposed now as coinciding in position with the magnet, and his head to the north.

87. *The same otherwise.*

The resistance being very inconsiderable in this experiment, it may be exhibited in a more simple manner. For instance, instead of piercing the foot of the cup, as in the figure referred to, it will be sufficient to use a tea-saucer, or any other shallow vessel, and to bring a strong magnet as near to it as possible under the table, when the motion will take place precisely in the same manner as above.

By this means also we may establish a most important fact; viz. that it is indifferent, as to the result of the experiment, what may be the position of the magnet; that is to say, if we keep the extremity of it as nearly as possible under the centre of the vessel, we may hold it either vertical or horizontal, or incline it in any angle, and at any azimuth, without greatly changing the rate of the rotation; it being always understood that the magnet should be of considerable length, in order that its other pole may not affect the motion of the wire. This result ought necessarily to be obtained, for in explaining the cause of the motion of the magnet about the wire, in Experiment X., we have made no reference to the position of the magnetic particles themselves; the motion, according to the principles we have adopted, would take place exactly the same (except as far as regards the mechanical difficulty) if the magnet could have been placed horizontally intead of vertically, and therefore the rotation of the wire about the magnet ought to be the same in both cases; viz. with the magnet placed either vertically or horizontally, and consequently also at all intermediate angles of inclination. This result was supposed by Mr. Barlow to be at variance with the theory of M. Ampere; but the latter philosopher, as well as M. Savary, has shown that it is in no-wise contradictory, but confirmatory of the doctrine in question.

EXPERIMENT XII.

88. *Exhibiting the two preceding rotations by Mr. Faraday's apparatus.*

The machine for the exhibition of these motions, according to Mr. Faraday's construction, is shown in

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* The small metal cup at C is soldered to the wire, and having a little quicksilver in it, furnishes the best means of making the contact, the ends of the wire being amalgamated for that purpose. It is not, however, actually necessary to employ this mode, as the simple contact of the wires is sufficient; but we have always found the connection shown in the figure to succeed best.

Fig. 50. Mr. Faraday's apparatus described.

fig. 50. ABCD is a stand of wood, E F a brass pillar, FG a fore arm or projecting piece of brass, through the extremity of which passes the wire L H K; at L, there is a sort of ball and socket joint; the socket being in the upper part, and the ball fitting it, on the small wire L *m*. Both the socket and ball are amalgamated, and a piece of silk fixed to the ball, or head of the wire, passes through a hole drilled in the wire L H, and by which the smaller wire is suspended, thereby preserving the contact, and leaving to the latter a perfect freedom of motion; *a b* is a glass cup having a hole through its foot, into which is inserted a copper tube, soldered to a copper disc just the size of the bottom of the glass, and which disc is cemented to the foot of the latter.

The wire Z *z* is also soldered to another copper disc, upon which the glass rests; and by which the contact is carried on from Z to the quicksilver in the cup, and thence to the wire *m* L; lastly, a small magnet *n s* is inserted into the copper tube, passing through the stem of the glass above mentioned.

The foot of the cup *c d* is pierced, and discs of copper applied as in the cup *a b*; but the wire passing through the foot is solid, and to it is fixed, by a short string, the small magnet *n s*, which is thus free to revolve about the descending wire H K; quicksilver, as in the preceding cases, being poured into the cup, till the wire H K is slightly immersed in it at K. The contact with the battery being now made at Z and C′, the motions will take place as described in the two last experiments; viz. the magnet *n s* in the one cup will revolve about the wire K, while the wire L *m* will at the same time be revolving about the other magnet *n s*.

If the cup *c d* be placed where the cup *a b* is represented, then the magnet and wire being both free, they will revolve about each other, and thus produce a pleasing variety in the experiment.

Fig. 51.

A section of this machine is shown in fig. 51. A more simple apparatus for exhibiting the rotation of the wire about the magnet has been already described in art. 30.

Experiment XIII.

89. *To exhibit the rotation of a magnet on its axis by the effect of a galvanic wire.*

Fig. 52. Rotation of a wire on its axis.

Let A B D E, fig. 52, represent a cup of glass or wood, N S a magnet, having at its lower extremity a fine steel point, inserted in the agate *a*; *b c* is a thin slip of brass or ivory, having a hole through which the magnet passes freely, and by means of which it is kept perpendicular: at the upper extremity N of the magnet, is a thin cylinder, as a piece of quill, forming a cup or reservoir *z* to receive a small quantity of quicksilver; and into this is inserted the wire Z, amalgamated at its lowest point, and C *c* is a stout wire passing through the side of the cup into the quicksilver. Then, the contact being made at C and Z, the magnet will begin to revolve on its axis, with a very astonishing velocity, and continue in motion while the power of the battery lasts.

This pleasing experiment is due to M. Ampere, who employs only a piece of platinum attached to the magnet, to produce, by its superior gravity, a vertical position of the latter in the mercury; the upper wire being then inserted into the quicksilver in the cylinder *z*, and the other wire into the cup C, the motion is produced exactly as above described: the greatest freedom of motion is, however, given by the apparatus shown in the figure.

The explanation of this rotation is very obvious according to the hypothesis we have adopted, for the tangential force of the wire acting upon the magnetic particles on the surface of the magnet, must necessarily produce the rotation in question, on precisely the same principles as the magnet is made to revolve about the wire in the fifth experiment.

Experiment XIV.

90. *To exhibit the rotation of a galvanic wire on its axis by the action of a magnet.*

Fig. 53. Rotation a wire o its axis.

Let N S, fig. 53, be a magnet, represented as broken in the figure, but which is fixed, in the experiment, in a foot, in order to keep it vertical; and let *a b c d* be a light hollow copper or brass cylinder having a steel point passing downwards into the agate cup *f*, fixed to the upper end of the magnet; and let *e* be a small tube or quill fixed on the wire passing through the top of the cylinder, holding a little quicksilver, and receiving into it the descending conducting wire Z. A B is a piece of wood turned to fit on the cylindrical magnet N S, which has a hollow groove on its upper surface to receive a quantity of quicksilver, into which the lower edge of the cylinder *a d* is slightly immersed, the surface being covered with weak dilute nitric acid. A C is a wire passing into the quicksilver. It is obvious that thus (the contact being made at Z and C) the galvanic circuit is carried from Z through the cylinder *a b c d*, thence to the quicksilver, and hence again through the wire A C to the other extremity of the battery, whereby the cylinder *a b c d* is made to become a part of the conducting wire, and it will be found to revolve on its axis with a great velocity, fully equal to that of the magnet in the last experiment; the direction of the motion, with the arrangement shown in the figure, being from left to right, to a person coinciding in position with the magnet.

If we conceive the cylinder to consist of an infinite number of wires, the explanation of this motion is the same as in Experiment XI. This experiment is due to Mr. Barlow.

Experiment XV.

91. *To exhibit the rotation of the wire and magnet when both are combined in one system.*

Rotation the wire and magt in combi tion.

In the preceding experiments relative to the rotation of the magnet and wire, the one has been fixed, and the other free, or they have both been free, as in Experiment XII. In this experiment the two are invariably connected, but the rotation still takes place. E F C D, fig. 54, is a cup filled with mercury, N S a magnet loaded with a piece of platinum T S to give it verticality in the fluid. L M is a wire, with a small cup of mercury Z, for making the connection with the battery. The ends L M of the wire pass through a piece of card, or any light substance, (in which also the magnet is fixed,) and thence descends into the mercury. The connection being now made with the battery at Z and C, the wire L M will rotate, as in the last experiment, carrying with it the magnet N S.

Fig. 54.

This experiment, which is due to Mr. Faraday, shows that the tangential force which causes these rotations does not take place between any fixed point in the magnet and wire, but that it exists between the particles of the fluids in the two bodies, and that the magnetism being accumulated at N, the action is the same, whether the magnet be in motion or at rest, as we ought *a priori* to have expected according to the hypothesis advanced in art. 43.

Experiment XVI.

92. *To exhibit a quicksilver vortex by means of a galvanic wire and magnet.*

Quicksilver vortex exhibited.

To perform this experiment it is only necessary to take any shallow non-conducting vessel and put into it a quantity of pure mercury, into which is to be inserted the conducting wires Z, C, proceeding respectively from the zinc and copper sides of the battery. And if now the north end of a strong magnet be brought under the vessel, the quicksilver round the wire C will begin to revolve about the same, forming a beautiful vortex, the direction of the motion being from left to right. If the magnet be removed under the other wire, the same kind of motion will be produced, but its direction will be reversed, and the same change of motion will take place, of course, in each case, by changing the end of the magnet.

The explanation here is precisely the same as in Experiment XIV.; the moveable part of the conductor in this case, owing its mobility to its fluid nature, whereas in the former it is due to the peculiar mode of suspension.

This very elegant experiment is due to Sir H. Davy.

Experiment XVII.

93. *To exhibit the rotation of the galvanic wire independently of the galvanic battery.*

Fig. 55. M. Ampere's rotatory apparatus.

For this purpose we must employ the apparatus exhibited in fig. 55, where A B C D is a small copper vessel about $2\frac{1}{2}$ inches high, and the same in diameter; *a b c d* is another small cylinder of copper, of the same height, soldered to the former vessel at its lower end *d c*, a hole being left in the bottom of the former to receive it. The cylinder *a b c d* is therefore open, and will admit a cylindrical magnet to be passed up, and it will at the same time hold a quantity of dilute acid within the space A D *d a b c* B C: $z\,z'$ is a zinc cylinder, very light, of rather less altitude than the copper one. To the cylinders *a b* and $z\,z'$ are soldered two copper wires, as shown in the figure, the upper one having a steel point proceeding from E downwards and resting in a small metal hole at F, and consequently the cylinder $z\,z'$ will be free to move upon its point of suspension F.

Things being thus prepared, and the acid placed in the cell as above described, insert through the interior cylinder the north end of a strong cylindrical magnet, and balance the whole apparatus upon it; when immediately the zinc cylinder will begin to revolve, with a greater or less velocity, according to the strength of the acid, the freedom of motion, and the power of the magnet. We have frequently with this simple apparatus produced a motion amounting to 120 rotations per minute. The only difference, between this and the other rotations above described, is, that the galvanic power is here produced by the apparatus itself, instead of having recourse to the battery.

For it is obvious that the wire from $z\ z'$ to E, may be considered as a conductor proceeding from the zinc, and the wire from *a b* to F, as one from the copper side of the battery; and consequently, the same effect is to be expected here as in the preceding cases. It is unnecessary to add, that with the north end of the magnet upwards, the motion is from left to right, and the contrary with the magnet reversed.

This experiment is due to M. Ampere.

94. *The same otherwise, by Mr. Marsh.*

Mr. Marsh's rotatory apparatus.

Fig. 56.

A very pleasing addition has been made to this apparatus by Mr. J. Marsh. It consists in having a second point descending from F, which is made to rest in an agate cup, fixed on the top of the magnet, fig. 56, and upon which the whole machine is balanced, having a perfect freedom of motion; and to preserve this balance, the magnet is placed vertically in a foot. The machine being now charged with acid, a compound motion takes place, the zinc cylinder revolving in one direction and the copper vessel in another, producing thus a very pleasant effect; the latter, however, is by no means so rapid as the other, in consequence of the weight of the acid, and in fact that of the whole machine being supported on the lower point.

Experiment XVIII.

95. *To show the effect of a horse-shoe magnet on a freely suspended galvanic wire.*

Oscillatory motion of galvanic wire, by Mr. Marsh.

Fig. 57.

Let Z *z*, fig. 57, denote a part of the galvanic wire, freely suspended by the chain connection at *o*, proceeding from the zinc end of a battery, its lower extremity being amalgamated and slightly immersed in a reservoir of pure mercury, having a connection at C with the other extremity of the battery. N S is a horse-shoe magnet, posited as shown in the figure.

The contact being now made at C and Z, the hanging part of the wire *o z* will be thrown out of the mercury into the position $o\,z'$; the contact being thus broken, it falls by its own gravity into the mercury, by which means the contact being renewed it is again projected, and so on with an extraordinary rapidity; and if the position of the magnet be reversed, or the contact be changed, the direction of the motion will be changed also, but the effect will be the same.

This singular motion may be still explained by the hypothesis that has been advanced; for the wire having a tendency to pass round the north end of the magnet to the right hand, and round the south end to the left hand, is urged by equal forces directly in a line with the open space of the magnet, the equality of the two forces preventing the rotatory motion about either, but both conspiring to give to the wire the rectilineal motion which has been described.

This experiment is also due to Mr. J. Marsh.

Electro-Magnetism

EXPERIMENT XIX.

96. *To exhibit a wheel and axle rotation by means of a horse-shoe magnet.*

Fig. 58. Wheel and axle rotation.

The machine by which this motion is produced is represented in fig. 58, where A B is a rectangular piece of hard wood, C D an upright wooden pillar, D E a piece of stout brass or copper wire, and *a b* a somewhat smaller wire, soldered upon it at F, on the lower side of which the wheel W, of thin copper, turns freely; *h f* is a small reservoir for mercury, sunk in the wood, and *g i* a narrow channel running into it: H H is a strong horse-shoe magnet. Mercury being now poured into the reservoir *f g*, till the tips of the wheel are slightly immersed in it, and the surface covered with weak dilute nitric acid, let the connection with the battery be made at *i* and D, and the wheel W will immediately begin to rotate with a great velocity. If the contact be changed, or if the magnet be inverted, the motion of the wheel will be reversed; but in general, the best effect is produced when the wheel revolves inwards. The suspension of the wheel, which is found to answer the best, is shown in fig. 59. This, which is due to Mr. Barlow, is a necessary consequence of the motion described in the last experiment, by which it was suggested, and the motion is explained on the same principles.

Fig. 59.

EXPERIMENT XX.

97. *To exhibit a compound wheel and axle rotation with two horse-shoe magnets.*

Fig. 60. Compound wheel and axle rotation.

The machine for producing this motion is shown in fig. 60; A B G D is a rectangular piece of board, having two grooves, about half an inch deep, cut in it parallel to its length. C *p*, Z *q*, are two wires having cups for connection at Z and C, and each passing into its respective groove *a b*, *c d*, filled with mercury; into which are slightly immersed the points of the wheels W W′: these being fixed on an axle W W′, and resting upon the two supports *m n*, *r s*, brought to a fine edge at *n* and *s*, in order to reduce the friction as much as possible, and to give the greater freedom of motion. N S are two horse-shoe magnets, posited as in the figure, with the like poles interior and exterior of the wheels.

The apparatus being thus prepared, and the contact made at Z and C, the wheels will begin to rotate, and in a very short time will acquire a velocity exceeding very considerably any of the motions hitherto described.

It is unnecessary to say that by changing the contact, or by inverting the magnets, the direction of the rotation will be also changed. The usual precaution of covering the surface of the mercury with weak dilute nitric acid, will increase the rapidity of rotation, but it is not actually necessary in this case. This experiment is also due to Mr. Barlow

EXPERIMENT XXI.

98. *To produce a rotation of the galvanic wire by means of the terrestrial magnetism.*

Rotation produced by terrestrial magnetism

This interesting experiment is due to Mr. Faraday, and it proves, in the most satisfactory manner, the influence of the terrestrial magnetism in the production of a rotatory motion. It is performed as follows: a very light copper, or platina wire, about six inches long, is suspended very freely from a larger wire proceeding from either end of the battery, by means of the chain connection described in several of the preceding experiments, and at its lower extremity a small piece of cork is attached in order to keep the wire buoyant on a basin of pure mercury, about ten inches in diameter. The wire by which the above small moveable piece is suspended, is then so much depressed that the proposed revolving wire slopes at an angle of about 40° with the horizon; in this state the circuit of the battery is completed through the mercury in the basin and the other conducting wire, when immediately the short wire commences a rotation, as it would do about the south end of a magnet, but in a proportionally less degree, as the directive power of the earth is less than that of a magnet of the kind here supposed.

Course Experi ments.

This similarity of action naturally leads us to infer a similar cause, and that this cause is no other than the terrestrial magnetism; still, however, in order to render this conclusion the more indisputable, Mr. Faraday changed the inclination of the wire, making it first equal to the angle of the dip; and when under these circumstances the wire was placed so as to coincide with the dip itself; viz. when placed in the magnetic meridian, sloping from south to north, there was no motion; and when the angle was still farther increased, so as to exceed the angle of the dip, it was projected in two different directions, according as it was made to slope to the north or to the south, which is precisely what ought to be the case on the supposition of the motion being caused by the magnetism of the earth.

Fig. 61 62.

For let $o\ z$, $o\ z'$, in fig. 61 and 62, represent the freely suspended wire in the plane of the meridian, sloping respectively to the north and south; and let N S in both figures denote the direction of the terrestrial magnetism; then it is obvious in the first of these figures, that whether the slope be towards the north or towards the south, it will be always on the same side of the line N S, and will in both cases be projected in the same direction with respect to the observer, situated, as supposed in art. 49, and consequently in opposite directions as referred to the circular rotation of the extremity z or z'. But when the slope is less than the dip, then the wire in its two positions being found on opposite sides of the line of direction, and passing still to the same hand of an observer situated in the wire, a rotation will ensue similar to those that have been described in our Experiments XI. and XII.

EXPERIMENT XXII

99. *To exhibit the action of two galvanic wires on each other.*

Fig. 63. Attracti and repu sion of g vanic wi exhibite

The apparatus which may be employed for this purpose is shown in fig. 63, where A B represents a rectangular board, and D, E, two upright pieces of wood, carrying each a cross-piece at top with several holes for receiving the cups *m m′*, *n n′* which by this means may be placed at different distances; a little mercury is poured into each of these so as to communicate with the wires inserted through the side of the cup, and terminated with fine points. The

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wires $w\ a\ a'\ w'$, $w\ b\ b'\ w'$ are bent as shown in the figure, and have small holes drilled at $a\ a'\ b\ b'$, whereby they may be hung freely upon the points of the wires $m\ m'$, &c. and carrying small weights $w\ w'$, &c. in order to bring the points of suspension to correspond as nearly as possible with the centre of gravity, whereby the wires are moved by the least force. The conducting wires from the extremities of the battery Z and C are terminated as represented in the figure, and being each brought to the respective cups, so that $z\ z'$ are respectively inserted in the cups $m\ n$, and $c'\ c$ into the cups $m'\ n'$, the circuit will be made through the two wires $a\ a'$, $b\ b'$ in the same direction, and these being free to move about the points in the respective cups, will be strongly attracted towards each other, even at the distance of several inches.

Let now the branch z of the conducting wire Z z be lengthened so that it may pass round the board and be inserted in the cup n', while z' is inserted in the cup m as before; lengthen also the branch c of the conducting wire C c, passing it round the board and dipping it into the cup n, while c' is immersed in m' as at first; by this means the circuit passes from z to c along the wire $b\ b'$, and from z' to c' along the wire $a\ a'$; in short, the circuits in the two wires are now made in opposite directions, and the wires experience and exhibit a mutual repulsion. Hence we learn, that two galvanic wires, parallel to each other, and in which the circuit is made in the same direction, are attracted towards each other; but they are mutually repelled when the circuit passes in opposite directions, a result first deduced by M. Ampere, and which he has made the foundation of his theory of electro-magnetism, by assuming that the powers exhibited by artificial and natural magnets are due to currents of the galvanic fluids circulating in planes perpendicular to their axes; and, that those currents, when parallel to each other and passing in the same direction, are attracted, and when in opposite directions, repelled. We have already offered some observations on this theory, in art. 70, *et seq.* It is certainly highly ingenious, and will, most probably, lead to important results.

100. *Experiments exhibiting various rotations induced by thermo electric-magnetism.*

Marsh's ap-
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tation.

At the conclusion of Professor Cumming's paper, referred to in art. 57 on Thermo Electricity, he has proposed a combination, intended to produce rotation by the action of a magnet on a rectangle of platinum and silver. Mr. Marsh, of Woolwich, in endeavouring to copy this apparatus, found that it had, a slight tendency to rotation, only not sufficient to give to it a very decided character. He then attempted some little variation in the form of the rectangle, and a different application of the magnet, and ultimately succeeded in producing a very rapid rotation. An account of these combinations and experiments on them, was afterwards published by Mr. Barlow in No. 307 of the *Philosophical Magazine*, to which work we are indebted for them. They are stated nearly as follow:

On constructing a machine precisely from the description given by Professor C., it was found that it had indeed a tendency to revolve, but so small that it was very difficult, if not impossible, to exhibit the phenomenon in a satisfactory manner. It turned out, however, while carrying on the experiment, that, although a magnet in the interior of the wire would not produce any but a weak tendency to rotation, a magnet applied exterior to it was capable of producing the most decided effect, as will be seen as we proceed to describe the following experiments.

Course of Experiments.

Fig. 64, 65, 66, 67.

For this purpose four rectangles, fig. 64, 65, 66, 67, were made of platinum and silver combined, as shown in the figures, where the thicker lines indicate silver wire, and the lighter ones the platinum; a ring being formed below to admit the prop upon which they were to revolve; and a fine steel point brazed to the upper side to rest in the agate on the top of the prop. The stand with a rectangle suspended is shown in fig. 68, where A B is a board, $c\ d$ a brass prop with its agate at top, and N S a magnet placed as nearly as possible to the wire. The spirit-lamp being now applied at D or E, the rotation will commence, either to the right or left, according to circumstances, and which will be reversed by reversing the pole of the magnet. Fig. 69 shows the same stand with two magnets.

Fig. 68.

Fig. 69.

These being premised, the reader will easily follow the detail of the following experiments, observing that when the motion is said to be to the right or left, he must imagine himself coinciding in position with the wire about which the machine turns.

Exp. 1. The rectangle, fig. 64, being applied upon the stand, fig. 68, and the lamp at E, the rectangle was projected to the right till D reached the lamp; it was then propelled back again, and after a few oscillations it remained at rest at right angles to its first position.

Exp. 2. The rectangle adjusted as before, and the lamp applied at D, the wire was projected to the *left* with similar results to the preceding.

Exp. 3. The rectangle adjusted so that D was next the magnet, and the light then applied at D. The wire projected to the *right*.

Exp. 4. The rectangle still in the same position, but the light applied at the other extremity. The wire was projected to the *left*.

Exp. 5, 6, 7, 8, were made under precisely the same circumstances with the rectangle, fig. 65; and the results were similar, but much weaker, and the motions all reversed.

Exp. 9, 10, 11, 12, were made with the rectangle, fig. 66. The motions the same as with the rectangle, fig. 64, except that generally a rotation was obtained when the light was applied as in Experiments 2 and 4.

Exp. 13, 14, 15, 16, were still the same experiments, but with the rectangle, fig. 67. The results were as in the above case, but reversed in respect to direction, and inferior in force.

A similar set of experiments was made with the south pole of the magnet opposed to the wire, and the results were similar, but all in the reverse direction.

As it was obvious from these experiments that the rectangle, fig. 66, either from its more accurate balance, or from the nature of the combination, was the most powerful, it was alone made use of in the following experiments, in which two magnets were employed.

Exp. 17. The rectangle, fig. 66, being suspended as shown in fig. 69, and the lamp applied at E, a rotation immediately commenced to the right, which soon increased to thirty revolutions per minute.

Exp. 18. The rectangle adjusted as before, and the lamp applied at D, the rotation to the left, at the rate of thirty revolutions per minute.

Fig. 70.

Fig. 71

Exp. 19. The compound rectangle, fig. 70, was now suspended and opposed to the north end of the magnet, as in fig. 71, and the lamp applied successively at E, D, G and F. The following were the results:

Lamp at E, rapid rotation to the right.
Lamp at D, rotation to the left, thirty per minute.
Lamp at G, rotation to the left, thirty per minute.
Lamp at F, no tendency to rotation.

Exp. 20. The magnet reversed, the lamp applied as before.

Lamp at E, rapid rotation to the left.
Lamp at D, rotation to the right, thirty per minute.
Lamp at G, no tendency to rotation.
Lamp at F, rotation to the right, thirty per minute.

Fig. 72.

Exp. 21. The same experiments were repeated with two magnets with contrary poles opposed, as shown in fig. 72.

The results as above, but more rapid: in the last experiments there were obtained about thirty revolutions per minute, but it was impossible to count them in these, when two strong magnets were employed.

Fig. 73.

It should be observed that in no case could any strong tendency to rotation be observed when a magnet was employed for a support, and the exterior magnet removed; fig. 73, in which one branch is carried further from the magnet, showed the greatest tendency.

Fig. 74.

A pleasing exhibition of a compound motion of this kind is shown in fig. 74, in which N S is a horseshoe magnet with an agate at each pole to rest the wire in, and L a lamp which serves to heat each compound rectangle. The motion in this case is not so rapid as in the former, but it is very pleasing, and will continue as long as the lamp burns.

Let us now endeavour to trace the theory of these motions. It must already have struck the reader as remarkable, that out of the four positions in which the lamp may be applied in the double rectangle, (fig. 71,) two of them give a rotation in one direction, and one of them in an opposite one, and that at the fourth point there should be no tendency to rotation whatever, but on the contrary a decided direction; this latter point is to the right of the north pole, or to the left of the south pole of the magnet, the observer assuming his position to coincide with the axis of motion, as already suggested in the preceding part of this article.

Let us, then, examine whether the hypothesis hitherto employed, will be sufficient to explain this remarkable fact.

The platinum being positive to the silver; when the lamp is applied at the union of the two metals, the fluid will be transmitted through the silver wire under the same circumstances as in a galvanic apparatus, with two plates, it is transmitted through the conducting wire from the copper side to the zinc; it ought therefore, when thus transmitted, to project the north pole of the magnet to the left, the observer now coinciding in position with the wire through which the circuit passes. Or the magnet being fixed, and the wire free as in our case, this latter ought to be projected to the right hand. Thus referring to fig. 71, and conceiving the lamp to be applied at E, the point E ought to be projected to the right hand of the observer, looking towards the magnet, while the points F, D, and G (the circuit in these being descending) ought to be projected to the left, the observer conceiving himself coinciding in position with these respective wires, and always looking towards the magnet. On the contrary, when the light is applied at F, then the circuit being ascending at F, and descending in all the other branches, this ought to be projected to the right, and all the others to the left; and so on, for any wire to which the lamp is immediately applied: and of course the contrary to all this ought to happen when the south pole is applied. Let fig. 75, 76, 77, and 78, represent the four applications of the lamp as stated in Experiment 19; and the several arrows the direction of rotation as excited by the magnet and lamp in these four cases. Then it is obvious that in fig. 75, answering to the case of the lamp applied at E, the tendencies to rotation are all in one direction, and we ought therefore to expect, as is actually the case, the rotation to be very rapid. In fig. 76, two of the forces are in one direction, and two in the other; and therefore if these forces were all equal, we ought to have no motion. But the force at D is very considerable in comparison with that at F or G, both on account of the immediate application of the lamp at E, and the division of the circuit into three branches at O; and the direction of the two latter forces on the respective levers, which being oblique are necessarily less effective in producing rotation. Again, the force at E is also considerable in consequence of the proximity of the magnet; so that the superior forces at D and E, conspiring in direction, will overpower the other two weak and oblique forces, and produce a very considerable rotation, although inferior to the former.

Fig. 75, 77, 78.

In fig. 77, the forces at E and G will be the superior forces; and as they conspire in direction, they will overpower the two inferior forces at D and F, which are opposed to them, and a considerable rotation will again ensue.

In fig. 78, the two superior forces also conspire, but with this peculiarity, that the moment the motion ensues, and the arm F arrives at F′ and E at E′, the direction of these two forces no longer assists in giving rotation, these being then both in the direction of the radii from the centre, and the resultant acts to bring the machine directly towards the magnet, and thereby to convert the rotation into direction, which the experiment strongly exhibits.

When the south pole of the magnet is opposed to the wire, all these directions of motion will be reversed, and then of course the point of neutralization will be at G, fig. 77; which explains the apparent anomaly of the point of no action being to the right hand of the north pole, and to the left of the south pole. In fig. 77 we have seen that with the lamp applied at G the motion is to the left; and when at E, as in fig. 75, it is to the right; it follows, therefore, that between these two there ought to be some position of equilibrium as G′, fig. 77, and where no motion of course ought to ensue. But in this case, instead of the forces at G′ and E′ being directed *from* the centre as in the case of fig. 78, they are directed *to* the centre. So that this state of equilibrium differs from the former in this,—that in the former, the equilibrium is one of *stability*, and in the latter of *instability*, and consequently very difficult to exhibit: in fact, the slightest inclination of the flame of the lamp in this situation of it, will give rise to a slow rotation in either direction according to the circumstances of the case. The same principles will enable us to explain the increase of acceleration produced by two magnets with their opposite poles applied as in fig. 69 and 72, and the cause of the non-action of a central magnet, except as in the apparatus of Professor Cumming, where one of the branches is carried further from the centre; in which case a slight tendency to rotation is exhibited equal to the difference of the two opposite forces.

We see thus the marked difference between the electro-magnetic rotations, produced by the application of the lamp, as in the cases above, and those produced by the galvanic machine; in the latter case it is essential to have the magnet central, whereas in this the magnet must be exterior to produce the desired effect; and the reason is obvious (referring for example to our Experiment XIV.) for here, and in all similar cases, the fluid being transmitted from the centre passes down the several branches in the same direction, and is therefore acted upon by the central magnet all in one sense; whereas in these, the fluid being ascending in one branch, and descending in the other, the forces on one side counterbalance those on the other, and the machine remains quiescent.

Since the publication of the above experiments in the work referred to, Mr. Marsh has contructed the little apparatus, fig. 74, so that it may be placed horizontally, as in fig. 79; by which construction the necessity of employing two magnets, in any case, is completely avoided.

101. At art. 81 we have mentioned a portable apparatus, constructed by the above ingenious artist. An account of this has just appeared in the 41st volume of the *Transactions of the Society of Arts*, to which we are indebted for the following description:

"The whole apparatus is included in a box fourteen inches and a half high, fifteen inches broad, and ten inches and a half wide, which, when folded out, forms a convenient table for the operator. Fig. 80 is a perspective view of the box ready for use, the flap *a* being raised up and supported by the leg *b*, which screws into it. The voltaic battery, with its appendages, occupies about half the box, and consists of a plate of copper, with a plate of zinc on each side. Fig. 82 and 84 are a front and transverse view of the battery; the two exterior or zinc plates are united at each corner by metal fastenings, and the intermediate or copper plate is cut away at the corners just sufficiently to prevent it from contact with the fastenings of the zinc plates, and is secured in its position by pieces of wood: *i i* are two copper feet upon which the battery rests when in action. Two brass pipes *c* and *z* are soldered, the former to the copper plate, the latter to one of the zinc plates; they are intended to hold a little mercury, for the purpose of forming a perfect connection between the conductors *c* and *z*, fig. 80, and the battery; in order still farther to secure the connection, the ends of the conductors that are inserted into the pipes are first tinned, and afterwards amalgamated, as well as the other ends on which the spiral wires fig. 88, forming the poles of the battery, are fixed. The battery, when not in use, is lodged in the cell *e*, fig. 80 and 81, which is lined with wood and varnished; the two jointed handles, by means of which it is raised, being laid down into notches cut in the partition between the two cells. The cell *d* is somewhat wider than the other, and is lined with sheet copper; into this the exciting fluid (dilute muriatic acid) is poured when the battery is intended to be put into activity, and the united copper and zinc plates being raised, by means of the two handles, out of the cell *e*, are to be gently let down into the fluid, resting on the bottom of cell *d*, by means of the two copper feet *i i* already mentioned. By this arrangement the battery forms a series of three copper and two zinc plates, the lining of the cell forming the two exterior copper plates, and consists of about eight square feet of metallic surface. Two pieces of varnished wood, *g h*, fig. 81, are fixed to the sides of the cell to prevent the zinc plates from coming in contact with its copper lining, a small tray *f* is also placed on the flap *a*, in order to retain any fluid which may be accidentally spilled during the experiment.

Course of Experiments.

Fig. 88.

Fig. 81.

"Fig. 84 shows the general arrangement of that part of the box, covered by flap *a*, fig. 80, in which the different articles of apparatus are deposited. The lowest compartment, represented more at large in fig. 85, contains a pair of horse-magnets, a cylindrical magnet, a pocket compass, some spare copper wire, and two tin boxes, in one of which are contained iron filings, in the other spiral wires of copper, tinned and amalgamated. Over this is placed the lower shelf, fig. 86 and 87; the under projections of which secure in their places the articles already mentioned. The three upper shelves, fig. 89, 90, 91, are cut out in the forms represented, in order to admit, in the most secure and compact manner, the various pieces of apparatus described and figured in Mr. Barlow's *Treatise on Electro-Magnetism*, to which the reader is referred."

Fig. 85.

Fig. 86 and 87.

Fig. 89, 90, 91.

We must here conclude our treatise on this infant science, which at present has furnished many highly curious and interesting results, and which, in the course of a few years, will, in all probability, lead to important discoveries relative to some of the most mysterious natural phenomena, particularly all those connected with Terrestrial Magnetism.

The works we have consulted, in writing the preceding treatise, have been referred to as we proceeded; they may, however, be generally enumerated as below: Phillip's *Annals of Philosophy*; Tiloch's *Philosophical Magazine*; *The Edinburgh Philosophical Journal*; *The Journal of the Royal Institution*; *The Transactions of the Royal Society*; *The Transactions of the Philosophical Society of Cambridge*; *Recueil d'Observations Electro-Dynamiques*, by M. Ampere; and Barlow's *Essay on Magnetic Attractions*, 2nd edition. A Memoir has also been published by M. Savary on this subject, of which M. Ampere speaks very highly; but which we were unable to obtain in time to avail ourselves of it in the composition of the foregoing treatise.

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ELECTRICITY.

Historical Sketch of the Origin and Progress of Electricity.

In attempting to give a short abstract of the history of that branch of Physics now universally termed Electricity, it will be perceived that a single fact observed in the earliest ages, and as far as our information can reach, at first recorded by the Greek philosophers, has by the subsequent addition of analogous phenomena, created and given name to a separate and important science.

Thales. B.C. 600.

Thales of Miletus, who flourished about 600 years before the Christian era, is reported by subsequent writers to have described the power developed in amber by friction, by which it was enabled to attract bits of straw, and other light bodies; and an attempted explanation of this phenomenon is given as one of his philosophical dogmas.

Theophrastus. B.C. 321.

In the treatise of Theophrastus upon stones, we have the earliest description extant of this property, "*ἐπεὶ δὲ καὶ τὸ ἤλεκτρον λίθος, καὶ γὰρ ὀρυκτὸν το περὶ Λιγυστικὴν καὶ τούτων ἂν ἡ τοῦ ἕλκειν δύναμις ἀκολουθείη.*" Theoph. *de Lapid.* p. 134, Hill's edit. Speaking also of the *Lyncurium*, he says, "*ἕλκει γὰρ ὥσπερ τὸ ἤλεκτρον οἱ δέ φασιν οὐ μόνον κάρφη καὶ ξύλον, ἀλλα καὶ χαλκὸν καὶ σίδηρον, ἐὰν ᾖ λεπτός ὥσπερ καὶ Διοκλῆς ἔλεγεν.*" p. 124.

Pliny. A.D. 70.

It does not appear that Pliny's knowledge upon this subject, extended beyond that of Theophrastus: he states of pieces of amber that "*attritu digitorum acceptâ, vi caloris attrahunt in se paleas et folia arida, ut magnes lapis ferrum.*" Plin. lib. xxxvii. cap. iii. and "*nec folia autem aut stramenta in se rapere, sed æris aut ferri laminas:*" like Theophrastus he also mentions the *lapis Lyncurius* as possessed of the same property. In the same chapter he adds, "*In Syria quoque fœminas verticillos inde facere et vocare harpaga, quia folia, et paleas, vestium fimbreas ad se rapiat.*" Similar quotations might easily be adduced from the writings of Priscian and Solinus.

[illegible] A.D. 218.

Salmasius, in his commentary upon the latter author, asserts that *karabe*, the word by which amber was known among the Arabs, is said by Avicenna to be of Persian origin, and to signify the power of attracting straws. (*Hyl. Iat.*)

ristotle. C. 341.

The ancient naturalists were well aware of another interesting electrical phenomenon in the shocks of the torpedo. Aristotle says that "this fish causes or produces a torpor upon those fishes it is about to seize, and having by that means got them into its mouth, feeds upon them." He further adds, that this fish "hides itself in the sand and mud, and catches those fish that swim over it by benumbing them, and of this some have been eye-witnesses: the same fish has also the power of benumbing men." Pliny says that "this fish if touched by a rod or spear even at a distance, paralyses the strongest muscles, and binds and arrests the feet however swift." *Nat. Hist.* xxxii. ch. i. Galen the physician has given a similar description, (*de locis affect.*) Oppian describes the organs by which the animal produces this effect, (lib. ii. ver. 62;) Oppian. A.D. 204. and Claudian has a short poem upon the subject. Claudian. A.D. 395. The medical writers speak of applying the shocks of the torpedo for the cure of diseases. Scribonius Largus, Scribon. Largus. A.D. 50. (cap. xli.) relates, that Anthero a freedman of Tiberius, was by this means cured of the gout. Dioscorides advises the same remedy for inveterate pains of the head. (lib. ii. art. Torpedo.) Further notices of this application may be found in Galen, *Simp. Medic.* lib. xi. Galen, &c. A.D. 144. Paulus Ægineta, lib. vii. Such is a summary of the knowledge of the ancients upon electricity; but the curious reader will also find much interesting matter on this subject in a dissertation by Dr. Falconer, contained in the third volume of the *Memoirs of the Manchester Society*, wherein it is rendered exceedingly probable that the use of conductors for attracting lightning from the clouds, was not unknown even in these early times.

The scanty fragments of information which the literature of the middle ages affords on this and every other scientific subject may be passed over in silence, and it may fairly be asserted, that from the time of Pliny until the end of the fifteenth century, no advance whatever took place in the branch of natural philosophy now before us. There is however mention made of more than one electrical phenomenon in the scholia upon Homer by Eustathius, Bishop of Thessalonica, Eustathius. A.D. 1160. about A. D. 1160; one of these passages relating to Walimer, the King of the Goths, who commenced his reign, according to Du Fresnoy, A. D. 415, is too singular to be passed by unnoticed. "*Βαλίμερ ὁ Θευδερίχȣ πατηρ, ὁ κατακρατήσας Ἰταλίας φασὶν ἁπάσης, τοῦ οἰκείς σωματος σπινθῆρας ἀπέπαλλε. καὶ τις δὲ σοφὸς παλαιός φησι περὶ ἑαυτοῦ, ὅτι ἐνδυομένου ποτε καὶ ἐκδυομένου αὐτοῦ, σπινθῆρας ἀπεπήδων ἐξαίσιοι, ἔστιν ὅτε καὶ κτυποῦντες, ἐνίοτε δε καὶ φλόγες ὅλαι κατέλαμπόν, φησι, το* ἱμάτιον μη καίουσαι." Eustath. *in Il.* E. p. 515, lin. 4, ed Rom.

"Walimer the father of Theodoric, (uncle πατρως?) who conquered as they say the whole of Italy, used to emit sparks from his own body; and a certain ancient philosopher says of himself, that once when he was dressing and undressing himself, sudden sparks were emitted occasionally, crackling; and sometimes he says, entire flames blazed from him, not burning his garment."

Although it is clear that philosophical speculations upon the natural properties of matter, were by no means valued or pursued in what we should now call a truly scientific manner; yet the following singular passage from St. Jerome may afford a sufficient proof that the facts which had been before recorded, were neither lost nor forgotten. "*Arguit in hoc loco Porphrius et Julianus Augustus, vel imperitiam historici mentientis, vel stultitiam eorum qui statim secuti sint Salvatorem, quasi irrationabiliter quemlibet vocentem hominem sint secuti: cum tantæ virtutes, tantaque signa præcesserint, quæ Apostolos antequam crederent, vidisse non dubium est. Certe fulgor ipse, et majestas divinitatis occultæ quæ etiam in humanâ facie relucebat, ex primo ad se videntes trahere poterat aspectu. Si enim in magnete lapide et succinis hæc esse vis dicitur, ut anulos et stipulam et festucas sibi copulent; quanto magis Dominus omnium creaturarum ad se trahere poterat quos vocaba.*" Sti. Hieronymi, Presb. lib. i. *Com. in Matt.* cap. ix.

Gilbert. A. D. 1600.

As a science justly entitled to the name by resting upon judicious reasoning and careful experiment, electricity may be said to have originated with the publication of the treatise on magnetism by Dr. Gilbert, A. D. 1600, in which treatise as connected with his subject, several new electrical phenomena are brought forward. After adducing the supposed origin of the name *electrum* for amber, ("*Græci vocant* ἠλέκτρον *quia ad se paleas trahit attritu calefactum, inde* ἅρπαξ *dicitur et* χρυσοφόρον *ab aureo colore, &c.*" Gilbert *de Magnete*, cap. ii.) he then gives a fair history of the state of philosophical knowledge in his own time, in the following curious sentences. "*Multi sunt auctores moderni qui de succino ex gagate attrahentibus paleas, aliis vulgo incognitis scripserunt, et ab aliis exscripserunt, quorum laboribus bibliopolarum officinæ farciuntur. Ætas nostra multos libros protulit, de abditis, de abstrusis, de occultis causis, et miraculis, in quibus omnibus succinum et gagates abducuntur allicientia paleas, sed nullis rationibus ab experimentis, et demonstrationibus inventis, tantum agunt verbis, rebus ipsis majorem caliginem inducentibus,* (*silicet*) *abdite, miraculose, abstruse, recondite, occulte.*" cap. ii. The substances known to possess the attractive property he thus enumerates; amber, gagates, (*Jet.* "*a loco et amne nomine Gagas in Cilicia ad cujus ostia seu fauces ad mare prope urbem Plagiopolum hic lapis reperitur,*" Diosc. lib. v. cap. 92.) diamond, sapphire, carbuncle, iris gemma, (*quartz crystal,* "*quia quando radios solares excipit arcum cœlesti similem jacit in parietem,*" *Johns. Lex. Chem.*) opal, amethyst, vincentina, (*Bristol stone,*) beryl, and crystal. Glass, especially if pellucid, paste for false gems, glass of antimony, slags of furnaces, and belemnites; also sulphur mastic, sealing wax, hard resin, and arsenic but feebly, sal gem, lapis specularis, (*mica,*) and roche alum; the three last scarcely at all under the unfavourable circumstances of a moist atmosphere. He says that these substances not only attract straws but all metals, wood, leaves, stones, earths, water, and oil, in short all other substances. These experiments he directs to be performed by bringing the excited body near to the end of a light needle of any metal balanced, and turning freely on a pivot like the magnetic apparatus. Dr. Gilbert next speaks of the three kinds of attraction mentioned by Galen, and enters into a refutation of the opinions of some of his predecessors on the cause of electrical attraction, such as Cardan, Pictorius, and Fracastorius. He states that there are many substances which do not possess electrical properties except upon friction; but that there are other bodies which however well polished do not attract at all. Such are, emerald, agate, carnelian, pearls, jasper, chalcedony, alabaster, porphry, coral, marble, Lydian stone, flints, hæmatites, smyris, *(emery or corundum,)* bones, ivory, hard woods, such as ebony, cedar, juniper, and cypress, metals and natural magnets.

Having also observed how unfavourable was the presence of moisture or moist air to electrical experiments, he draws a parallel between electrical and magnetical attraction, which though sometimes erroneous, is for the most part ingenious, and must at that time have been instructive. His theory of electrical action supposes the emission of certain effluvia, which having previously existed in the amber or other electrified substance, were called into activity by the friction, and he compares the nature of these attractions to that of cohesion. Much that is erroneous in Gilbert's reasoning arises from the uncertainty which then existed respecting the true nature of bodies; all solids were considered as having formerly been fluids which had then become hardened, and as a specimen of the use he makes of this hypothesis, the following sentence may be selected. "*Resina terebinthina liquida non allicit, teri enim non potest; at si concreverit in mastichen allicit.*" Gilbert then proves that the electric fluid does not affect the air, by showing that if its action takes place through the flame of a small taper, the flame does not move, and he infers that therefore the air adjacent to it is not put into motion. Mentioning the phosphorescent light produced by rubbing together two pieces of flint in the dark, he says that the silex emits an inflammable matter convertible into heat and light, but that the electric fluid is widely different, being so much attenuated that it does not take fire nor serve for combustion. The effect of fire in destroying the power of some electrics is also noticed, but the experiments of Gilbert on this point are fallacious.

Ba

The hypotheses of Sir F. Bacon, Cabæus the Jesuit, Sir Kenelm Digby, Gassendi, and Des Cartes, may be passed over in silence, because however ingenious their speculations may have been, they are proved by subsequent facts to be erroneous; and produced no addition to the experimental department of the science.

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Mr. Boyle will however demand some further degree of attention: his *Experiments and Notes about the Mechanical Origin of Electricity*, published in 1675, contains additional matter for the history of our subject. He speaks as follows of the opinions of the writers whose names we have just mentioned. "It is not necessary that in this paper where I pretend not to write discourses but notes, I should consider all that has been, or I think may be said for and against each of the above-mentioned hypotheses; since they all agree in what is sufficient for my present purpose, namely, that electrical attractions are not the effects of a mere quality, but of a substantial emanation from the attracting body; and it is plain that they all endeavour to solve the phenomena in a mechanical way, without recurring to substantial forms and inexplicable qualities, or so much as taking notice of the hypostatical principles of the chemists. Wherefore it may suffice in this place that I mention some phenomena that in general make it probable that amber, &c. draw such light bodies as pieces of straw, hair, and the like, by virtue of some mechanical affections either of the attracting, or of the attracted bodies, or of both the one and the other." p. 7. Boyle having found the advantage of warming the electric bodies, explains this by saying "that it is known that heat by agitating the parts of a fit body solicits it as it were to send forth its effluvia, as is obvious in odoriferous gums and perfumes, which being heated, send forth their fragrant steams both further and more copiously than they otherwise would." His next experiment teaches him that to warm a piece of amber first, and then to submit it to friction, was the most effectual mode of excitement.

The power of amber to remain in its attractive or excited state some time after the cessation of friction, was established by experiments upon a delicate steel needle suspended after the method proposed by Gilbert; and it appeared advantageous that the surfaces of the electric should be as smooth as possible; but Mr. Boyle mentions one diamond in its rough state which exceeded all the polished ones in his possession. To the list of known substances capable of electric excitation he added the following. The resinous cake remaining after the partial evaporation of turpentine, the dry residuum after the distillation of a mixture of petroleum and strong spirit of nitre, glass of antimony, glass of lead, white sapphire, white English amethyst, the almost diaphanous spar of lead ore, the carnelian, and a green stone which had been supposed an emerald, but which from its hardness, the lapidary considered a sapphire; to the two last Gilbert had denied this property. He describes also very philosophically the electric attraction of the curls of some ladies hair. In a very just spirit of investigation, he ascertained that the converse of all the experiments upon the relative motion of the attracted and attracting body was also true; namely, that if the substance to be attracted were fixed, and the excited electric capable of motion, their union would still take place. In order that he might ascertain whether electric attraction depended upon the ambient air, he introduced an excited mass of amber into the receiver of an air pump. The amber was suspended over a straw or feather, and after the exhaustion of the vessel, was lowered towards the light body which was attracted as before. We now know, however, that had this experiment been performed with rigid accuracy, a contrary result would have ensued. Mr. Boyle's theory, as might be expected from the passage we first quoted from his work, did not greatly differ from those of his immediate predecessors, he supposed that the electric body emitted a glutinous effluvium, which laid hold of, or became entangled in the pores of small bodies in its egress, and upon its return to the body which had emitted it, carried them back with it.

Otto Guericke.

Contemporary with Mr. Boyle was the celebrated Otto Guericke, a burgomaster of Magdeburg, the inventor of the air pump, who also became a distinguished contributor to electrical science. His experiments were commenced by casting a globe of sulphur in a glass sphere; the glass was then broken and removed, the sulphur mounted upon a revolving axis in a wooden frame, and excited by the application of the hand. With this instrument he verified the experiments of preceding writers, and discovered in addition the light and sound accompanying strong electrical excitation; the light he compares to that produced by breaking lump sugar in the dark.

Guericke clearly demonstrated that a light body, after it had by attraction been brought into contact with an excited electric, was repelled by it, and could not be again attracted, until it had been touched by some other body. The most important of his experiments is one which has only met with a full explanation subsequent to the most improved state of our science; he found that if light bodies were suspended within the sphere of action of an excited electric, they themselves became possessed of electrical excitation. Thus if threads were suspended near to his excited globe, they would be repelled by the approach of his finger; and that a feather suspended and repelled by the globe always turned the same side towards it. *Experimenta Magdeburgica*, lib. iv. ch. xv.

Newton.
1675.

In the year 1675, Sir Isaac Newton communicated to the Royal Society a singular and important electrical experiment; from which it would appear that he was the first who remarked that excited glass would attract light bodies, even to the surface opposite to that upon which it had been rubbed. "Having laid upon a table a round disc of glass about two inches broad in a brass ring, so that the glass might be one-eighth of an inch from the table, and then rubbing the glass briskly, little fragments of paper laid upon the table under the glass, began to be attracted and to move nimbly to and fro. After he had done rubbing the glass, the papers would continue a considerable time in various motions; sometimes leaping up to the glass and resting there awhile, then leaping down and resting there, and then leaping up and down again; and this sometimes in lines seemingly perpendicular to the table, sometimes in oblique ones; sometimes also leaping up in one arch and leaping down in another, divers times together, without sensibly resting between; sometimes skipping in a bow from one part of the glass to another, without touching the table; and sometimes hanging by a corner, and turning often about very nimbly, as if they had been carried about in the midst of a whirlwind, and being otherwise variously moved, every paper with a different motion. Upon his sliding his finger on the upper side of the glass, though neither the glass nor the enclosed air below were moved, yet he observed that the papers as they hung under the glass, would receive some new motion, inclining this way or that way, according as he moved his finger." Birch's *History of the Royal Society*, vol. iii. p. 260. The phenomena of electricity are also for other purposes alluded to in Newton's *Optics*, p. 314—327, ed. 1721.

Haukesbee
1705.

In just chronological order the researches of Mr. Haukesbee next claim our attention. In the year 1705 he noticed that mercury shaken in glass vessels produced a light visible in the dark, and that when the density of the air is diminished to one-half, the light becomes much more brilliant. He ascertained that this was caused either by the friction of mercury against glass, or of the air, but could not satisfy himself by which. In his next series of experiments he showed that light was produced by rubbing together in vacuo, amber and flannel, glass and flannel, glass and oyster-shells, woollen and woollen, and glass with glass. He ascertained also that if glass be rubbed against glass, either in the air or under water, the same evolution of light takes place; but he could not produce the same effect with any of the other bodies tried. It is singular that in these and many such among his early experiments, it did not occur to him that the light thus produced was electrical. He produced a vivid light by rubbing an exhausted glass globe with his hand; also by agitating mercury in a varnished vessel, under an exhausted receiver; by breaking loaf sugar, or a lump of calomel, and at first supposed that these effects were due to some peculiar quality in the glass. By the admission of air into the glass globe, the light was diminished; but if the friction was continued, and a person brought his finger near to the globe, the light appeared on the point of the finger. His experiments on attraction and repulsion were performed by a wire-ring, round which he had tied short pieces of thread. When this hoop was brought near to an excited globe or cylinder, he found that in whatsoever position it was placed with regard to the excited electric, the threads all were attracted towards the centre of the globe, or towards a point in the axis of the cylinder. When in this state of things, he presented his finger to the threads; if very near, they would be attracted to it, but if the finger were about an inch from the threads, they would be repelled. He then tied two threads to the axis of a globe and cylinder, and found that when the globe or cylinder was turned round and excited by friction, the threads diverged in straight lines from the axis. The threads also were repelled by a finger held near to them without the glass, even though the finger did not touch it; but sometimes they would suddenly jump towards the finger. He found also, that when the threads were enclosed within the glass, if he blew upon it at a distance of three or four feet, the threads would by their motion manifest that electric attraction was excited in the glass. If the threads were suspended freely in an unexcited globe, and any excited electric was brought even within a considerable distance of the exterior of the globe, attraction was developed. As this experiment did not succeed equally well in moist weather, he concluded that "the moisture on the surface of the glass prevented the free passage of electricity through it." In attributing this diminution of effect to the influence of moisture he was correct, but he erred as to its mode of action; from considering that the electric attraction passed through the substance of the glass, whereas in fact the side of the glass opposite to that approached by the excited body, became itself electrified by induction, a matter to be hereafter explained.

In Mr. Haukesbee's later experiments, he had arrived at the construction of the electrical machine, not differing essentially from some in use at the present time. His machine was in fact a glass globe, instead of the sulphur ball of Guericke; capable of being whirled round in a wooden frame. When exhausted of air, and turned briskly, the application of his hand would produce a strong light on the inside; and by readmitting the air, light appeared on the exterior also; but with this singularity, that it appeared to stick to his fingers, or to other bodies held near the globe. By bringing an exhausted globe near to an excited one, he found that a light was produced in the former, which soon disappeared; but which immediately reappeared in great beauty if the latter were again put in motion. Mr. Haukesbee considered, that he had established that when friction is performed in *vacuo* no electrical attraction could be produced; but that though this effect required the agency, both of external and internal air, yet that light required the presence of but one of them for its evolution; because "either a glass globe full of air rubbed in *vacuo*, or with its air exhausted and rubbed in *pleno*, would either way produce a very considerable light." The following experiment must at that time, and indeed long after, have been considered one of great singularity. More than half of a glass globe was coated with sealing-wax, exhausted and put in motion: on application of the hand without, for the purpose of excitation, the form of the hand was distinctly seen on the inner concave surface of the wax; thus appearing to give transparency to the wax, which in some parts was an eighth of an inch thick, and in the thinnest parts would only just allow the flame of a lighted candle to be seen through it in the dark. Even when the wax did not strictly adhere to the glass the effect remained the same. The same experiment succeeded when pitch was used instead of wax; and Haukesbee was surprised to find that on the admission of air, all parts of the interior of this mixed surface, attracted equally as well as if not coated at all. With melted flowers of sulphur, this experiment did not succeed, but with common brimstone it did. If the quantity of this sulphur was greatly increased, the light became four times as great, but the distinctness of the image of his fingers was diminished. By admitting a small quantity of air to the globe thus prepared, the light disappeared from the coated part, but remained upon the uncoated part. The following experiments were made upon the electrical effects of some other substances. A wooden cylinder was coated thickly with sealing-wax, and submitted to friction upon the machine. By the hoop and threads it was shown to be strongly attractive, leaf brass also was attracted by this apparatus. In comparing these effects with those of the glass cylinder, Haukesbee comes to a conclusion, which we now consider erroneous: "so that the electrical qualities of these two bodies, (glass and wax,) are the same as to all the most general properties. They differ only in degrees, the effluvia of glass producing more powerful effects than those of wax." And yet he afterwards observes, from experiments made in the dark, that "none of the luminous matter would be communicated to one's finger when held near it; whereas in the lights produced from glass it was otherwise." In the same manner cylinders coated with sulphur and resin were tried; the former had not a very powerful effect, but the latter while warm exceeded glass, and even attracted leaf brass without friction, at the distance of an inch or two. By trials in *vacuo*, he found that sulphur would emit no light, but that sealing-wax emitted more than even when freely exposed. Mentioning the active motion produced in bits of leaf brass lying on a table, and covered by a flat-bottomed glass, when an excited stick of sealing-wax is held above; he says, "this shows the penetration, subtilty, and very great activity of the effluvia (at least of these) electrical bodies." Enough has now been selected from Mr. Haukesbee's writings, to exhibit him in the light of a very zealous and successful experimentalist. Of the difference between the two electricities he had no suspicion, though at times he was struck by results dependent upon their distinction alone, and in such cases he did not fail to point out the discrepance of his results. The cases by which he convinced himself, that the electrical power was not intercepted by solid bodies, were as we now know frequently the effects of electricity by induction, but were ascribed by him to the subtile nature of the *effluvium*, which enabled it to pass through the substance of glass and other bodies. The term effluvium which he employs, accords well with his notion of its being a substantial emanation; and even now, though we are unable to prove that it is a material substance, we continue to employ the words *electrical fluid*, as a convenient verbal designation. We reason upon it as if it were an actual tangible substance, and apply the physical laws of matter to account for its distribution and arrangement upon the surfaces of bodies, as if its particles could be made the immediate objects of our senses. Mr. Haukesbee did not remark the distinction between electrics and non-electrics; for after trying in vain to produce electric light by the friction of brass, he observes, that "if there be any such quality as light to be excited from a brass body, all the attrition of the several bodies I have used for that purpose, have been too weak to force it from it. And, indeed, considering the closeness of the parts of metals, and with what firmness they adhere, entangle, and attract one another, a small degree of attrition is not sufficient to put their parts into such a motion as to produce an electrical quality, which quality, under the forementioned circumstances, I take to be the appearance of such a light in such a medium."

Wall. During the publication of the above experiments, Dr. Wall communicated in a paper to the Royal Society, certain other electrical phenomena. He speaks of Boyle's artificial phosphorus, leading him to amber; and seems to consider the light emitted by it upon friction in the dark as his own discovery, and then adds "Amber directed me to the diamond, from its being electral as the other, which is also a natural phosphorus, or rather a noctiluca exceeding all others, and may without any exception, be called a mineral phosphorus." He also mentions the luminous properties of gum lac and sealing-wax; but as Haukesbee's experiments appear in the *Phil. Trans.* from 1705 to 1711, and Dr. Wall's in 1708, while Guericke's had been some time in print, the claims of all these to the discovery of electrical light must give place to those of the Magdeburg experimentalist.

Grey. The history of electricity must now pass over a space of about ten years, in which no additions of importance were made to the science. That the discoveries of Haukesbee should not have excited a greater interest, and impelled philosophers to further experiments, may appear singular; but Priestley has, with great appearance of probability, suggested that the brilliant discoveries of Newton, in other branches of science, might possibly have engrossed the whole attention of the scientific world, thus inducing a degree of neglect over all electrical inquiries. The *Philosophical Transactions* for 1720, contain the first of Mr. Stephen Grey's papers on electricity, followed by others in the years 1731 and 1732, 1735 and 1736. He first states, that having tied a down-feather to a small stick, and brought near to it an excited glass tube, the fibres of the feather which were at first attracted towards the glass, would on removal of the tube, attach themselves to the stick; he thence inferred, that some electrical property must have been communicated to either the stick or the feather. Hence he was led to inquire, whether if the feather were drawn through his fingers, it might not produce the same effect by acquiring some degree of electricity. In this experiment he succeeded, and by proceeding in a similar manner, he obtained indications of electricity in hair, silk, linen, woollen, paper, leather, wood, parchment, and gold-beaters skin. From some he obtained luminous appearances in the dark, but in most cases found it necessary to warm the substances before he submitted them to experiment. *Phil. Trans.* 1720, p. 107. The next series of experiments by Mr. Grey, contains a discovery of some interest, namely, that bodies in which electricity is not capable of being excited, might nevertheless receive it by communication from regularly excited electrics. He had failed in attempting to make metals electric by heating, rubbing, and hammering them; but yet as they would receive electric light from glass in the dark, he considered that they might receive general electricity also At this period it must be remarked, that attraction was considered the only absolute proof of the presence of electricity. In February 1729, Mr. Grey informs us he made the following experiments. He procured a glass tube three feet five inches long and nearly 1·2 in diameter. Its ends he closed with two corks to exclude the dust; he first established that by these corks, the attractive power of the tube was not diminished; and then found that a feather was attracted to the cork, as by the tube itself. To the cork he then affixed an ivory ball by a short stick, and then found that this attracted and repelled the feather even more strongly than the cork had done. The stick was then lengthened, and finally pieces of wire were substituted in its place, without any diminution of effect. The wire was found to attract the feather throughout its whole extent, but not so forcibly as the ball. For wires he then substituted strings, and instead of the ivory ball he suspended a great variety of substances; towards all of which he was able to attract small light bodies, by exciting the glass tube at the other end of the string. Having, by this mode of suspension, with canes, rods, and pack-thread, proved that he could convey the electro-attractive property a distance of fifty-two feet perpendicularly; he was desirous of attempting the same thing in a horizontal direction. In his first experiment he suspended a pack-thread upon nails affixed to a beam; but in this case though he failed in his experiment, he attributed the failure to the right cause, namely, that the beam had carried off the electricity. Mr. Wheler, to whom Grey had mentioned this difficulty, proposed to suspend the pack-thread by silken-threads; and the expedient was readily adopted by Mr. Grey, from a belief that the smaller substance of these threads, would, in a great degree, prevent the abstraction of the electrical power. The experiment was completely successful, and the effect produced at a distance of 147, and subsequently 293 feet. On the breaking of their silk lines of sus-

Wheler.

pension, wire was thought of as a substitute, being of still smaller diameter; but here again all effect was lost, and they therefore concluded, "that the success they had before, depended upon the lines that supported the line of communication being silk, and not upon their being small." Again returning to silk lines more judiciously affixed, they conveyed electricity a distance of 666 feet. In an experiment of this kind made without doors, they perceived that when the dew appeared in the evening, no effects could be obtained. *Phil. Trans.* 1731, p. 32.

It is conjectured by Priestley, that about the same time hair, resin, glass, and some other substances, besides silk, were discovered to be non-conductors. Magnetism was found not to interfere with electricity; and that even large surfaces, such as a map and an extended table-cloth might be rendered electrical; that electricity might be communicated in several directions at the same time; that a poker being heated, was not thereby prevented from receiving the effluvium. The next experiment related, is an interesting one, in which a hair line eleven feet long was affixed to a beam, with a leaden weight attached to its lower end. When the excited glass tube was brought near to the lower part of the hair line, but without touching it, the lead gave signs of electricity, by attracting brass leaf; but if the tube was held high up near to the beam, the effect did not take place. They then attempted to ascertain by solid and hollow cubes of wood of equal magnitude, whether the electric attraction were proportioned to the quantity of matter contained in the attracting bodies. Without coming to any decision on this point, Grey was of opinion, that the electricity passed through every part of the solid cube, though no part except the surface attracts. In his next trials, Mr. Grey electrified a wooden rod without touching it as he had done the hair line; he then tried the attractive power of metal hoops, suspended in different positions by hair lines, in order to show that the effect upon the hoops which were not touched by the glass tube, might be conveyed both in vertical and horizontal circles. In these and many such experiments, he was employing what we now call electricity by induction, but without being aware of the circumstance, and having no means of ascertaining the presence of electricity, beyond the attraction of light bodies, he could not recognise the difference of the two electrical states of bodies. Mr. Grey's next experiments embrace a totally different class of bodies. In order that he might ascertain the conducting power of liquids, he blew a common soap-bubble with a tobacco-pipe; and having electrified the pipe, he found that small pieces of Dutch metal were attracted by the lower pendent part of the bubble. Having suspended a boy by means of hair lines, he found that the human body is a good conductor; Mr. Wheler having proved the same of a chicken before. From such experiments Mr. Grey infers, that " animals receive a greater quantity of electrical fluid than other bodies;" and yet throughout all these attempts it never occurred to him, that the moisture in several of the substances was the cause of their conducting properties. At the close of the same paper, he mentions some results at which he had arrived, showing that different colours differed in their attractive properties; these, however, were proved by M. du Fay to be erroneous. The next paper in 1732, is to show that a body of water when placed upon an insulating stand of glass or resin, might by passing an excited tube over it a few times be made to exhibit electrical attraction; also that an excited tube held over small cups quite filled with water, would cause the water to rise up in conical mounds; and that a stream of light passed from the tops of these cones visible in the dark, carrying with it a small quantity of moisture which was deposited upon the surface of the tube. p. 230. Quicksilver was found capable of an elevation, similar in kind, but less in degree in consequence of its superior specific gravity. His next series of experiments was made upon nineteen substances, consisting of resins and sulphur, these he found after having been fused in an iron ladle and suffered to cool, acquired a strong electrical property; and by wrapping the bodies up in worsted, their power continued unimpaired until the time of his writing, which, with respect to some of them, included a space of four months. Their attractive property was manifested whenever required, by holding to them a stick with a bit of thread tied to the end of it. The most powerful of these was a cone of sulphur, cast in a large drinking glass, which, whenever the glass was lifted off, exhibited strong electrical properties; and in fair weather the glass would attract also. Some further essays, published about the same time by Grey and Wheler, in conjunction, add little to the real knowledge on this subject, and refer principally to different modes of varying the means of communication between the excited electric, and the attracting ball.

The discoveries of M. du Fay will for the present interrupt the series of Mr. Grey's papers. This excellent foreign experimentalist communicated his essays to the Academy of Sciences at Paris, in eight memoirs, published during the years 1733, 1734, and 1737; but he also transmitted a succinct abstract of his labours to the Royal Society, which is published in the *Transactions* for 1734. From this paper, as better suited to the brevity of our present purpose, we extract the substance of his discoveries. He found that " all bodies (metallic, soft, or fluid ones excepted,) may be made electric by first heating them more or less, and then rubbing them on any sort of cloth." He then mentions Mr. Grey's experiment of placing water upon an insulating stand, and electrifying it by the approach of an excited tube; and states that he found upon trial " the same thing happened to all bodies without exception, whether solid or fluid; and that for that purpose it was sufficient to set them on a glass stand slightly warmed or only dried;" and "that such bodies as of themselves were least electrical, had the greatest degree of electricity communicated to them at the approach of the glass tube." He then ingeniously proves that Mr. Grey's inference, of different coloured substances attracting differently, depended upon the colouring matter, and not upon the colour itself. The next experiment is to show that the pack-thread used in Mr. Grey's experiments, transmitted electricity much better by being wetted, and that it might be supported upon glass tubes instead of silk lines. Having suspended himself upon silk lines, in the manner of the child in Mr. Grey's experiments, he found that when he held the pasteboard disc on which was the gold leaf in his hand, no part of his own body would attract it, but that it would be attracted by any part of a second person, not so suspended. Also, that by the approach of another person's hand to any part of his body, a spark would pass from himself to the hand, and cause a pricking sensation to both parties. The Abbé Nollet, who accompanied him in these experiments, says he shall never forget the surprise this phenomenon occasioned to both parties. In repeating the experiments of Guericke, he says he discovered a very simple principle which accounts for a great part of the irregularities that seem to accompany most of the experiments on electricity. This principle is, "that all electric bodies attract all that are not so, and repel them as soon as they become electric by the vicinity or contact of the electric body. Thus leaf gold is first attracted by the tube, and acquires an electricity by approaching it; and of consequence is immediately repelled by it. Nor is it reattracted while it retains its electric quality. But if while it is thus sustained in the air, it chance to light on some other body, it straightways loses its electricity, and consequently is reattracted by the tube, which after having given it a new electricity, repels it a second time, which continues as long as the tube keeps its electricity. Upon applying this principle to the various experiments of electricity, one will be surprised at the number of obscure and puzzling facts it clears up." This application to the experiments of his predecessors Du Fay proceeds to make. In the next place he says, "Chance has thrown in my way another principle more universal and remarkable than the preceding one, which casts a new light on the subject of electricity. This principle is, that there are two distinct electricities very different from one another, one of which I call vitreous electricity, and the other resinous electricity. The first is that of glass, rock crystal, precious stones, hair of animals, wool, and many other bodies: the second is that of amber, copal, gum lac, silk, thread, paper, and a vast number of other substances. The characteristic of these two electricities is, that a body of the *vitreous electricity*, for example, repels all such as are of the same electricity, and on the contrary, attracts all those of the *resinous electricity*; so that the tube made electrical will repel glass, crystal, hair of animals, &c. when rendered electric, and will attract silk, thread, paper, &c. though rendered electrical likewise. Amber on the contrary, will attract electric glass, and other substances of the same class, and will repel gum lac, copal, silk, thread, &c. Two silk ribands rendered electrical will repel each other; two woollen threads will do the like; but a woollen-thread and a silk-thread will mutually attract one another. This principle very naturally explains why the ends of threads, of silk, or wool, recede from one another in form of a pencil or broom when they have acquired an electric quality. In order to know immediately to which of the two classes of electricity belongs any body whatsoever, one need only render electrical a silk-thread, which is known to be of the resinous electricity, and see whether that body rendered electrical attracts or repels it. If it attracts it is certainly of that kind of electricity which I call vitreous; if on the contrary it repels, it is of the same kind of electricity with the silk, that is of the resinous." *Phil. Trans.* p. 265.

M. du Fay concludes this paper by stating that a body so insulated, as to be capable of retaining electricity, continues to retain the same species of electricity which is at first communicated to it. He remarks, that in the case of two bodies similarly electrified for the exhibition of repulsion, there is to be this limitation, that the bodies be made equally electrical; for if one were weakly electrical, and the other strongly so, attraction would take place, be the kinds of electricity what they might. In this view of the question, that there are two distinct species of electricity, the continental philosophers have with some few exceptions remained to this day; but as we shall hereafter find, another theory was subsequently proposed by Dr. Franklin, which has also for its patrons some experimentalists of distinguished eminence.

In resuming the detail of Mr. Grey's experiments, contained in four papers communicated to the Royal Society in 1735 and 1736, we shall have little of importance to select. He repeated and varied the experiments of M. du Fay, and in company with Mr. Wheler and some others, observed the cone of electric light formed by diverging rays from the point of a metal rod attached to an electrified body. One passage in his writings has been deservedly selected to prove the sagacity of this very judicious experimentalist. Speaking of the effects of electricity communicated to insulated conducting bodies, he says, "Although these effects are at present but in minimis, it is probable in time there may be found out a way to collect a greater quantity of the electric fire; and consequently to increase the force of that power; which by several of these experiments, '*si licet magnis componere parva,*' seems to be of the same nature with thunder and lightning." It will hereafter appear how completely these predictions were verified in the discovery of the Leyden jar, and in Franklin's experiments with the electrical kite. The remaining researches of Mr. Grey may here be omitted almost without further notice It has been clearly shown that he was in truth a benefactor to electrical science; but in his last experiments upon the rotation of pendulous bodies from west to east, under circumstances of electrical attraction, he probably had deceived himself; some of these were communicated to Dr. Mortimer the day before his death, and this gentleman upon a subsequent trial seems to have thought that he had obtained results, similar to those of Mr. Grey. Mr. Wheler also together with some members of the Royal Society, undertook the examination of Mr. Grey's results, and at last gave it as his opinion, that a desire to produce the motion from west to east was the secret cause that determined the pendulous body to move in that direction, by means of some force impressed by Mr. Grey's hand, as well as by his own; though he was at the same time persuaded that he was not sensible of giving any motion to his hand himself.

From the papers of Mr. Wheler published about this time, he seems to have made a series of observations with results which led him to the same conclusion at which M. du Fay had arrived: and from the dates of their respective papers it would appear that each had established the same facts with regard to the opposite states of electrical excitation, independently of the other.

Desaguliers.

Eight memoirs in the *Phil. Trans.* comprise the labours of Dr. Desaguliers on this subject, and in 1742, the date which his last paper bears, he published an excellent essay on electricity, which gained the prize from the Bourdeaux Academy. Few new experiments of importance are brought forward by this writer; but he systematized and arranged the discoveries of his predecessors, introducing some judicious terms of nomenclature, which still continue to be employed. He first distinctly divided bodies into *electrics* and *non-electrics* or conductors; the former being glass and those substances capable of electrical excitation, and incapable of conducting the fluid from one body to another; the latter, including metals and such bodies as were not then thought capable of excitation, but which could convey away the fluid from other excited substances. He seems to have first decided that air belonged to the former of these classes, and showed that the conducting properties it sometimes exhibited, were the effects of water contained in it in the state of vapour; thus he accounts for the superior success of electrical experiments in frosty weather, and in dry states of the atmosphere.

Boze.

We have now arrived at a period in the history of electricity at which the Germans became zealous labourers in this branch of philosophy. The globe of glass which Haukesbee had introduced, and which subsequent electricians had very injudiciously neglected, was again employed by Mr. Boze, Professor of Philosophy at Wittemburg; he also introduced the prime conductor, suspending it from silken-threads.

Winkler.

Professor Winkler of Leipzic substituted a cushion for a rubber instead of the hand. In place of the globe Mr. Gordon, a Scotch Benedictine monk, and Professor of Philosophy at Erfurt, introduced a glass cylinder eight inches in length and four in diameter, to be turned with a bow. The principal object of the experimentalists of this period appears to have been the production of as powerful a spark as possible; and from thence the transition was easy to the ignition of combustible substances by its effect. Ludolf of Berlin appears to have first accomplished this by setting fire to the ethereal spirit of Frobenius.

Ludolf.

Ludolf the younger also showed, that the light seen in agitating the mercury of a barometer, was truly an electrical phenomenon, and that the glass tube became excited in consequence. Boze proved by many experiments, that the weight of bodies was not affected by giving to them, or abstracting from them, electricity. Several ingenious electrical toys, which will be hereafter described, date their origin from this period.

Miles.

Dr. Miles in 1745, observed the pencil of luminous rays proceeding from an excited electric, even without the approach of a conducting body.

Watson.

The same year (1745) brings us to the discoveries of Dr. Watson, the details of which are contained in the *Phil. Trans.* He first repeated the experiments of the Germans on the firing of spirits and gunpowder, by the electric spark. This had been performed by a person holding the substance in a metallic spoon, and thus receiving upon it the spark from the conductor of a machine. He reversed the experiment, placing the substance in contact with the conductor, or in the hands of an electrified person, and then produced ignition by receiving a spark from it. In 1746 he describes the difference of colour in the electric sparks, if received from different substances, and says that the fire is much redder from rough surfaces, such as rusty iron, than from polished iron or steel, however sharp the point from which it is taken. He supposed, however, that this difference was owing to some variation in the reflection of the light, rather than to any real difference in its colour. He next proves that the electric fluid suffers no refraction in its oblique passage through bodies; and that its passage through glass was much facilitated by the glass having been previously warmed. He showed that in electrifying conductors of considerable extent, electricity is first accumulated or developed at that part which is most remote from the excited electric. Also that electric fire is neither increased nor diminished by ordinary heat or cold; and that both smoke and flame were conductors of electricity.

Musche broeck,

The discovery of a method for accumulating and preserving the electric fluid in large quantities, appears to have been made in the year 1745, by Kleist a monk; and simultaneously by Muschenbroeck at Leyden, from which circumstance it still bears the name of the Leyden jar or phial. According to Dallibard however, the inventor's name was Cuneus. From the accounts handed down to us, it would appear that this great addition to electrical apparatus was the result of deliberate reflection, and if so, great credit is due to these sagacious experimentalists. Muschenbroeck and his friends observed that excited electrics soon lost their electricity by exposure to the atmosphere, which is replete with conducting matters of various kinds; they therefore supposed that if the electrified bodies could be surrounded by more perfect non-conductors, the change would be greater and more permanent. With these views, they attempted to change some water contained in a glass bottle, and at first with no very marked result. At length however when a communication had been made between the water and the prime conductor, and at the same time one of the party had held the outside of the bottle in his hand; on attempting to disengage the wire passing from the prime conductor to the water, he experienced a sudden shock in his arms and breast, which it would seem the party had not gone far enough in their speculations to foresee. We must here pass by the numerous absurd accounts which the repetition of these experiments produced; doubtless these early electricians may have given to each other some severe shocks, but the novelty of the circumstance aided by fear, can alone account for the marvellous descriptions of their effects. Watson made some important observations connected with this experiment. He noticed the flash of light which accompanies the discharge of the jar. He found that the power of the shock was *cæteris paribus*, as the surface of conductors in contact with the outside of the jar. Reasoning from this circumstance, Dr. Bevis suggested the application of tin foil to the outer surface of the jar, extending it almost to the top, in which case it was found as might be expected, that as powerful a shock was obtained, by touching this outer coating with wire, as if the hand were applied to the surface itself. Watson also found that the discharge proceeds by the shortest course, supposing it to have the choice of conductors equally good. Smeaton about this time suggested the coating a glass plane on both sides within an inch of the edge, and Bevis tried the experiment with complete success. On this hint Watson completed the electric jar in its present form, by coating the inside and outside equally with tin foil or silver leaf.

Wilson.

In Mr. Wilson's essay he informs us, that as early as the year 1746, he discovered a method for giving the shock to any part of the body without affecting the rest.

Smeato

He communicated also by letter to Mr. Smeaton his attempt to discover the law of accumulation of the electric matter in the Leyden jar, and found that it was in proportion to the thickness of the glass, to the surface of the glass, and to that of the conducting surfaces in contact with the inside and outside of the jar. In this same work, mention is made of Mr. George Graham's having discharged a jar, causing the shock to pass through several persons at the same time, by joining of hands, as is now common.

ton.

Mr. Canton found that if a charged jar were placed upon an insulating stand, a spark might be taken from the wire communicating with the interior, and from the exterior coating alternately, and that thus the jar might be entirely discharged. The publications of Nollet and Le Monnier exhibit at this period a view of the progress of electricity in France, but their experiments differ little from those of our own electricians of the same era.

The distance to which electricity might be conveyed, and the rate of its motion, were the points that next engaged the attention of both the English and French experimentalists. In France, the discharge of the Leyden jar was effected through circuits of nine hundred; and two thousand toises in length; in one experiment, the basin in the garden of the Tuilleries was taken into the circuit, having a surface of about an acre of water. M. le Monnier on trial could not find that however long the circuit, any appreciable time was occupied in the passage of the fluid. The researches of the English on this subject were conducted on a most magnificent scale. The party consisted of Mr. Folkes the President, and several Fellows of the Royal Society, with Dr. Watson at their head, as chief operator. They first received the shock by passing the wire along Westminster Bridge, and making the water of the Thames through its whole width, part of the chain of communication. In July 1747, they conveyed it by wires on land 800 feet, and by the water of the New River, at Stoke Newington, 2000 feet. Also 2800 feet by land, and by water 8000. It subsequently appeared, however, that here the fluid had taken a shorter course by traversing the intervening land. By further experiments made on the 5th of August 1744, at Highbury Barn beyond Islington, they found the fluid conveyed by dry land, and that the effect was much increased by insulating the conductors, as well as the persons who held the rods to receive the shocks. Their last attempt was to ascertain whether the electric shock were perceptible at a distance much greater than that to which they had before carried it, through ground perfectly dry, and to distinguish, if possible, the respective velocity of electricity and sound. On the 14th of August, 1747, the experiments were made at Shooter's Hill, when during the preceding five weeks only one shower of rain had fallen. The wire communicating with the iron rod which made the discharge, was 6732 feet in length, and supported upon baked sticks throughout, as also was the wire communicating with the coating of the jar, this wire being 3868 feet in length, the observers being distant from each other two miles. The result of the discharge demonstrated to the satisfaction of the parties present, that the circuit performed by the electric matter was four miles, viz. two miles of wire, and two of dry ground, the latter being the space between the extremities of the wires. A gun was discharged at the instant of the explosion, and the observers had stop watches to note the moment when they felt the shock, but as far as they could distinguish, the time in which the electric matter performed that vast circuit, might have been instantaneous.

Nollet.

The period with which we are now occupied, was one fertile in electrical research; it may be made to comprise the principal labours of Watson in England, and of Nollet in France. Of these the most important in theory is due to the former, who proved that glass tubes and globes did not contain the electric power in themselves, but were as he phrased it, "movers or determiners" of that power. This he discovered by finding that while he stood upon a cake of wax, in order as he expected, to prevent any of the electric power from discharging itself through his body to the floor, no spark could be obtained from his body, but that if a person not electrified held his hand near the tube, he himself received a shock of electricity, and sparks might be taken from him. The conditions under which electrical excitation may be effected with regard to the insulation or not of the rubbers and conductors, are principally the result of this gentleman's researches; he expresses his ideas on the subject, by laying it down as a law, that in all electrical operations, there is an afflux of electrical matter to the globe and the conductor, and likewise an efflux of the same electric matter from them. Upon this view, however, he shortly afterwards improved, observing that in the case of two insulated persons, the one in contact with the conductor, and the other in contact with the rubber, both would give sparks; but that either could communicate a much stronger spark to the other than to any bystander. The electricity of the one becomes more rare he says, than it naturally is, and that of the other more dense; so that the density of electricity between the two persons differed more than that between either of them and another person standing upon the floor. This discovery was in fact identical with that of the celebrated Dr. Franklin in America, who thus explained the theory of plus and minus electricity. Watson also proved that electricity passes through the substance of a conducting wire, and not along its surface, by coating a wire with a cement of wax and resin, and discharging a jar through it. The same was subsequently shown by M. Jallabert, Professor at Geneva, who at the same time proved ice to be a conductor.

Le Monnier.

In 1746 also, Le Monnier showed that electricity is not communicated to homogeneous bodies in proportion to their masses, but rather in proportion to their surfaces. The various memoirs of Watson, Winkler, Hales, Nollet, and Ellicot, inserted in the *Philosophical Transactions* about this period, are replete with interesting and well-directed experiments, many of these it is not in our power here to notice; but the ingenious experiments of the Abbé Nollet in some other branches must not be entirely passed over. He found that in open vessels electricity increased the evaporation of fluids, that it did not affect the power of the magnet, neither did it accelerate or retard the heating and cooling of bodies, and that it greatly accelerates the afflux of fluids through capillary tubes. Mr. Maimbray at Edinburgh had electrified two myrtle-trees during the whole month of October 1746, and concluded that vegetation had been accelerated thereby, as the plants put forth leaves and blossoms sooner than other specimens which had not been electrified. These results were confirmed by M.

Nollet, also by M. Jallabert, M. Boze, and the Abbé Menon. It was also proved by the latter gentleman that animals lost weight by being electrified for five or six hours together; his experiments were made upon cats, pigeons, sparrows, and chaffinches. In extending these experiments to human subjects the Abbé found that these also lost weight, and rather increased in appetite, with a slight feeling of fatigue. He could not perceive that they became sensibly warmer, or that the rapidity of the pulse was increased.

Pivati.

Connected with these applications of electricity, we must here mention, though but slightly, a number of extraordinary medical results, said to have been obtained by its agency. Johannes Francisco Pivati published at Venice, in 1747, the first of a series of errors and deceptions (whether intentional or not) which required much labour, and numerous elaborate experiments entirely to disprove. He enclosed a quantity of balsam of Peru in a glass cylinder, so that before its excitation no smell could be emitted. With this cylinder he electrified a man having a pain in his side. The patient returned home, fell asleep, and perspired; so effectually we are told had the virtue of the balsam been thus conveyed to the patient, that his clothes and his hair were impregnated with the balsamic effluvium. In another experiment a similar effect was produced upon a person in health, who was not made acquainted with Pivati's intention, and in whom the odoriferous emanation became perceptible to himself and others half an hour after. Winkler, of Leipsic professed to have repeated similar experiments with success. Pivati next began to apply these powers to medical purposes, he professes to have cured, or rather discussed an abscess in the foot of a young gentleman by electrifying him with a glass cylinder filled with certain drugs. His next patient was Signor Donadoni, Bishop of Sebenico, seventy-five years old, and greatly afflicted with the gout. The joints of his fingers had become fixed, and he had lost the power of bending his knees. Pivati tells us that he proceeded to the cure by filling a glass tube with discutient medicines, and so managing that the electric virtue might enter into the patient. The Bishop presently felt some unusual sensation in his fingers, and "in two minutes, his lordship opened and shut his hands, gave a hearty squeeze to one of his attendants, got up, walked, smote his hands together, helped himself to a chair, and sat down wondering at his own strength; and hardly knowing whether it was not a dream. At length he walked out of the chamber down stairs without any assistance, and with all the alacrity of a young man." This and another similar cure said to have been performed upon an old lady of sixty-one, may well account for the sensation that these experiments seem to have occasioned. Winkler, as we have before mentioned, professed to have verified them, and the English and French experimentalists immediately commenced a similar attempt. In this, however, they completely failed, and after receiving from Winkler some tubes properly prepared, these also were submitted to a fair trial; and the conclusion at which they arrived was, that electricity had no effect in forcing odoriferous effluvia through the substance of glass vessels. The zeal of the Abbé Nollet even carried him into Italy, that he might witness these wonderful performances for himself, but he also came back convinced that the odours were not transmitted through the glass, and that the enclosed drugs had no medicinal effect, although in certain cases of paralysis, &c. the electricity itself was clearly beneficial. Dr. Bianchini also of Venice published an elaborate refutation of these fallacious experiments; Winkler, *Phil. Trans.* vol. xlv. p. 262; Baker, *Id.* p. 270; and the refutation by Watson, *Id.* vol. xlvi. p. 348; Winkler, *Id.* vol. xlvii. p. 231; and Watson, *Id.* p. 236.

At length we arrive at the interesting and fertile period of Dr. Franklin's discoveries. Hitherto electrical researches had been confined to the philosophers of the old continent, but the twilight of a brilliant day now began to dawn in America. Whether we consider the importance of his researches, the patience of his investigations, or the candid and unassuming manner in which he promulgated them, we shall find ourselves compelled to assign to Franklin a distinguished page in the history of electricity. Even in his lifetime, a period when an author is never judged with the greatest candour, he excited the admiration of the philosophic world, and his writings were translated into most of the languages of Europe.

His first communication to Mr. Peter Collinson of the Royal Society is dated March 28, 1747, and his last letter on electrical subjects is in 1760. Although Watson had about the same time discovered, and published, the explanation of the real action of the glass and rubber, Franklin's first papers show that he had arrived at similar conclusions. He says, "the electrical fire is not created by friction, but collected, being really an element diffused among, and attracted by other matter, particularly by water and metals," and he proceeds to prove the truth of this hypothesis much in the same manner as Watson had done before him. Franklin's theory of plus and minus electricity was more fully explained, and in fact more clearly conceived than that of Watson. One sentence selected from his letter to Collinson will explain this theory with that brevity which suits our present purpose. "To electrise plus or minus, no more needs to be known than this, that the parts of the tube or sphere that are rubbed, do in the instant of the friction attract the electrical fire, and therefore take it from the thing rubbing; the same parts immediately as the friction upon them ceases, are disposed to give the fire they have received to any body that has less." It is probably owing to his clear and just explanations that this theory was considered entirely the discovery of Franklin, when in fact it was only Watson's more completely developed. This justly celebrated American did not attempt to slight the labours of his contemporary, but mentions them in his own description, only correcting what he considered an erroneous explanation of an experiment, on the part of Watson. The Leyden jar, the construction and discovery of which has been already noticed, received an easy explanation upon this theory, by supposing that when the jar was charged, the inner coating had received more than its ordinary quantity of electricity, and was therefore electrified plus, while the outer coating having had its ordinary quantity of electricity diminished, was electrified minus; and the retraction of equilibrium between these two reservoirs was accompanied by the spark and shock, or as it is familiarly phrased the jar is discharged. The converse explanation of the charging of the outside coating is precisely similar, but will be entered upon more fully hereafter. Franklin shows, clearly, that when the jar is charged, the outside and inside coating give evidence of possessing the opposite electricities, this he proved by the alternate attraction and repulsion of a cork ball. He made many experiments to show, that in charging a coated phial as much electricity was lost from one side as was gained by the other. Among Franklin's earliest experiments we find him examining the power of receiving and giving out electricity by bodies of different forms. He electrified an iron cannon ball, and found that to deprive it of its electricity, he might present a pointed rod of wire, which would silently abstract the fluid from the ball; but that a rod terminated by a ball, would not draw off the fluid except by bringing it very near to the shot and receiving a spark. If left by itself, the shot retained its electricity a considerable time in the air, but the charge was soon dissipated if a needle had been laid upon the shot. Thus, pointed bodies absorb and dissipate electricity with great rapidity, while obtuse bodies, large globes or planes, do not readily abstract electricity, nor yet do they readily part with it by mere contact of the air. Franklin was soon enabled to apply these canons to one of the most sublime discoveries that had ever crowned the efforts of human ingenuity.

Very early writers had compared the electric spark to the flashes of lightning, but perhaps the Abbé Nollet produced a more distinct statement of this suspicion than any preceding writer. He declares that he had long been meditating their points of analogy, and expresses a hope, that some one might pursue the investigation. Nollet, *Leçons de Physique*, vol. iv. p. 34. Whether this had been seen or not by Franklin, can not now be clearly ascertained, but this distinguished French philosopher attributes to Franklin the bold thought of verifying this hypothesis, and in the collection of the letters and essays of the American experimentalist, there is one without a date, but standing before that of July 28, 1750, in which he brings together under one view, numerous points of similarity between the electrical discharge and the flash of lightning. Of these the following are the most important. The lightning does not move in a right line, neither does the electric spark, if passing through any considerable space from one conductor to another, and from substances of irregular form. Lightning strikes the highest bodies, and most readily those that are pointed. Electricity also is more readily attracted and emitted by conductors of the same form. Lightning sets fire to combustible bodies; so does electricity. Lightning chooses for its mark and path the best conductor, so also does electricity. Both lightning and electricity are capable of fusing metals, and of rending non-conductors or imperfect conductors in their passage. Persons have been struck blind by lightning, and a pigeon which Dr. Franklin had intended to kill by the shock, was found to have withstood the discharge, but had lost its sight. Both discharges are capable of destroying animal life. Magnets had their polarity reversed, and common sewing needles were made magnetic, by suffering the electric discharge to pass through them, and similar changes had been recorded as the effects of lightning. Thus strongly impressed with a belief of the identity of these two phenomena, the natural and the artificial, Franklin anxiously waited the erection of a spire in Philadelphia, by which he proposed to verify the conjecture. In the meanwhile, however, impatience stimulated his ingenuity, and produced a substitute for the spire. This was no other than a kite made by stretching a silk handkerchief upon two cross sticks, and affixing a tail on the common principle. This he raised at the approach of a thunder-storm, and so fearful was he of the ridicule attaching to a failure, that his son was the only assistant in the experiment. At first no electrical appearances presented themselves, but at length some loose fibres of the hempen string by which the kite was elevated, began to stand out, manifesting electrical repulsion. The hempen string was tied to a silken cord, by which it was held, and a key tied on where the hempen cord terminated, served to distribute the electricity to jars or conductors according as the experiments might require. At first but feeble electrical effects were perceived, but when the string had become wet by a shower of rain, an abundant stream of electricity was produced. Afterwards the Dr. contrived a pointed iron conducting-rod and affixed it to his house, with a bell to give him notice when any atmospheric electricity was collected by his rod. Thus was this most brilliant discovery achieved, but as the Dr. had published his method and intentions, the same experiment had been successfully performed in France about a month before. It remained only that the application of the discovery to a purpose of practical utility should crown the work, and this did not escape the penetration of Franklin; he proposed the conductor such as is now in use, viz. a pointed rod of metal extending above the top of a building, and terminating in the earth, or in water, whereby a cloud highly charged with electricity, might be discharged in safety through the perfect conductor to the earth. Of this we shall have to speak more particularly hereafter.

The remaining experiments of Franklin are chiefly of a miscellaneous nature, and are intermixed with those of his friend Mr. Kinnersley at Boston in New England. It was the general opinion at this period, that an excited electric, was in fact surrounded by an atmosphere of electric fluid; but although the term fluid was, and still is made use of for the sake of convenience in description, it became a question with Franklin, how far the presence of this electrical atmosphere interfered with the ordinary atmosphere, usually considered to be in contact with all natural bodies. He satisfied himself, that the electrical atmosphere did not require the displacement of the other, by the following experiment. A thick wire passed through a cork into an air-tight phial; in the same cork there was also inserted a glass tube open at both ends, having in it a drop of red ink, by the motion of which any expansion or contraction of the air in the bottle was readily made apparent. On communicating a charge of electricity to the wire, or on again removing the same, no alteration was perceived in the position of the drop of ink; and therefore no air had been displaced from its natural position round the brass wire within the bottle. Mr. Kinnersley is said about the same time to have noticed the two contrary electricities of glass and sulphur, a fact which Du Fay had before remarked, and the state of electrical science at the time enabled him to identify them with the ordinary positive and negative electricity of Watson and Franklin.

Canton's experiments from 1751 to 1762.

Although it may slightly interfere with the chronological order of some contemporary experimentalists, it will be convenient next to bring together some of the most important of Mr. Canton's discoveries. Of these, that which perhaps tended most to the real advancement of electrical science, was the overturning an opinion which the electricians of that period had hitherto never doubted; viz. that by any given electric, the same species of electricity was invariably developed; thus, that glass always became excited by positive, and sealing-wax by negative electricity. Canton, however, showed that if a glass tube be made rough, by grinding its surface with sheet lead and emery, the friction of a woollen cloth upon it produced negative or resinous electricity. He subsequently found that even the smoothest glass would receive the same electricity by drawing it over the back of a cat. Some curious subsequent extensions of this discovery will be noticed in their proper place. Mr. Canton next proved, by the construction of a most ingenious apparatus, that it was possible to electrify a body of air in a state of rest; that thus, if dry, a part or the whole of the air in a room might be charged with either plus or minus electricity, and so remain for a considerable time. Some experiments which Canton had made upon the electricity, developed by removing glass and other bodies from mercury, into which they had been plunged, connected with the early observations of the electrical light exhibited by agitating the mercury of a barometer, led him to the discovery of an amalgam, formed of tin and mercury, as a powerful agent for the excitation of electricity when applied to the cushion of an electrical machine. The last, and by no means the least, among the researches of this very able philosopher which our plan permits us to notice, was the discovery, on which Guericke had in fact touched, that if any insulated body be plunged within the sphere of influence, or, as he phrased it, within the atmosphere of an excited electric, the former body became itself electrified, and with the electricity opposite to that of the excited body. In some cases, the electricity remained when the bodies were again separated, in others it did not so, and the investigation of these distinct and curious phenomena was undertaken by contemporary electricians, well worthy of the interesting task. Canton in England, Franklin in America, and Æpinus and Wilcke in Berlin.

Richman.

Franklin's experiments upon the electricity of the atmosphere and clouds had now been repeated and extended by the philosophers of every nation. There was in them a degree of sublime magnificence, which ever lured the bold to an attempt at ruling the thunder and the lightning of the sky; and scanty as must be our notice of many an acute and laborious electrician, the fate of Richman, who fell a martyr to the science, pleads strongly for one word of remembrance and commiseration. Professor Richman, of St. Petersburgh, was engaged in a series of experiments upon atmospheric electricity, and for this purpose he had constructed, with an iron rod affixed to the top of his house, and a chain descending to his study, a conductor for the reception of the electric fluid. On the 6th of August, 1753, during his attendance at a meeting of the Academy of Sciences, the approach of a thunder-storm induced him to return home for the prosecution of his observations. A draughtsman accompanied him, and it does not appear that any sufficient precautions had been taken to guard against over-powerful charges of electricity, which the conducting rod might intercept. There was attached to the apparatus a sort of electrometer, formed by a linen thread which traversed the face of a divided quadrant, and in some degree served to mark the degree of the electrical charge accumulated by the conductor. The thread was standing at four degrees, and as Richman was explaining to his companion the degree to which he conceived it might rise before any danger could ensue, a tremendous clap of thunder was heard, and the unfortunate Professor, stooping to examine the electrometer, received a discharge from the rod, which instantly destroyed him. Sokolow, the engraver, stated that the spark consisted of a ball of fire as large as his fist; it had to pass a space of about a foot, and struck the Professor upon the forehead. The engraver was at first too much stupifyed and benumbed to escape, and slightly injured by the fragments of melted wire which were dispersed about the room. A clock was stopped in the adjoining room, the door-posts were torn down, and the ashes scattered about the fire-place. On examination of the body, very slight appearances of injury were perceptible; a small livid spot upon the forehead, and another on the left foot, the shoe of which was burnt open, marked the passage of the discharge, of which the unfortunate philosopher had been the conductor.

Beccari

In 1753, Beccaria published, at Turin, a treatise *Dell' Elettrismo Artificiale e Naturale*. In many particulars his experiments were similar to those of Mr. Canton; he also noticed the communication of permanent electricity to the air in contact with electrified bodies. He showed that the electric fluid was not instantaneous in its passage through even the best conductors, the metals. He arranged a wire 500 feet in length, and observed that when electricity was communicated to one end of it, the other end did not give signs of electrical excitation till after one vibration of a half-second's pendulum. In the case of a similar circuit of hempen cord, five or six vibrations elapsed, but the time was diminished to three or four vibrations by moistening the cord. His experiments on the passage of the electric shock through fluids are highly interesting, although perhaps they may in some cases admit of explanations widely differing from those he assigned to them. He considered that air and the electric fluid were mutually repulsive, and that therefore when an electric spark passed from one conductor to another, the air was entirely displaced. He proved that water is a very imperfect conductor, and showed that in transmitting a shock through it, the volume of the water was a material consideration. Small tubes filled with water would scarcely transmit a shock, which larger ones suffered to pass with facility. There is in this matter a singular resemblance to the recent discoveries connected with common magnetism, and that developed by galvanic agency. In the transmission of an electric shock through an imperfect conductor, in the passage of magnetism through a metal bar between the poles of a common magnet, and in the transmission of electro-magnetism through wires, it appears certain that the larger the conductor is made, the more complete will be the transmission of the fluid. Beccaria exhibited the electric spark, even in its passage through water, by bringing the extremities of two wires very near to each other in a small glass tube filled with that fluid. At the instant of the discharge, these tubes burst in pieces with great violence, though frequently made of glass more than half an inch in thickness. To this author we are also indebted for a valuable series of experiments on atmospherical electricity. Sir Torbern Bergman, of Upsala, also verified Beccaria's experiments upon the imperfect conducting power of water, showing also that ice is a still worse conductor than water.

Delaval, Phil. Trans. 1759 to 1764.

Between the years cited in the margin, Mr. Delaval communicated to the Royal Society several curious experiments; these were principally directed towards ascertaining the conducting powers of the same body in different states. Thus he showed that although the metals were the best known conductors, their oxides were non-conductors. Several of the researches of this gentleman have a singular analogy with some others of the present day, whereby it is proved that the same subtance, undergoing a change of temperature, is at some given points of its heat a conductor, and at others a non-conductor.

Æpinus.

At this period M. Æpinus announced to the Berlin Academy the electricity of the tourmalin, produced simply by heating the gem, and he noticed the developement of the opposite electricities on opposite points of the stone. Mr. Wilson, the Duke de Noya, and Bergman, occupied themselves with further researches on this curious property. Symmer, *Phil. Trans.* 1759; and Cigna, *Mem. Accad. Tur.* 1765.

Symmer, Cigna.

The labours of Mr. Robert Symmer in this country, and those of Johannes Franciscus Cigna, though not precisely contemporaneous, may come under our notice at the same time, as the remarks of the latter are in fact but a continuation of those of the former experimentalist. Symmer, after describing the electricity produced by separating two stockings, the one of silk, the other of worsted, which have been worn a few minutes on the same leg, proceeds to vary the experiment. He obtained sparks, and charged jars, from stockings thus excited. Drawing the stockings through his hand proved an equally efficacious and a more convenient mode of excitation; and he found that a black stocking gave abundant signs of electricity, while a white one could scarcely be made to affect a delicate electrometer. Subsequently, he made use of two stockings both of silk, the one black, the other white, remarking that after the two had been passed through his hand very little electricity was manifested so long as the stockings were in contact, but on their separation very marked electrical effects were produced; the black stocking became highly negative, and the white one positive. Reasoning from this and several similar experiments, he was led to entertain certain theoretical views, which differed considerably from those of preceding electricians; he arrived, in short, at that theory which is now embraced by much the greater number of continental philosophers. As we shall have occasion to advert to this matter hereafter, it may be sufficient here to state, that Du Fay had considered the two electricities which he discovered, as not only totally different in themselves, but also totally independent of each other, and as it were distinct properties of natural bodies. Watson and Franklin had viewed them as different states of the same body, with reference to a given quantity of fluid always the same, and inherent in all non-conducting substances, in one case indicating excess, and in the other defect, from the natural standard quantity contained by the body. Mr. Symmer contended for the existence of two electric fluids, but, unlike Du Fay, he urged that they were always coexistent, were not independent of each other, and were simultaneously developed in every case of electrical excitation. The form of the bur which was raised by the passage of an electrical discharge through several sheets of paper, and in certain cases having tinfoil interposed, was pressed into the service of Symmer's reasoning, but is not now viewed as throwing much light upon the subject. Cigna, who repeated Symmer's experiments, and varied them, making use of ribands instead of the stockings, attempted an explanation of these phenomena upon Franklin's hypothesis, but expresses himself as being by no means satisfied of the superiority of one theory over the other.

We feel the more disposed to make specific mention of the theoretical views of Symmer, because they are the foundation of the theory of electricity which has at present the greater number of admirers; and because the French writers on this subject are inclined to forget the circumstance, and to attribute all the merit of this hypothesis to Du Fay. The Germans, however, who may be considered impartial judges, distinctly attribute the present prevailing theory of two fluids to Symmer. (Fischer, *Physique*, p. 223.) We should be most unwilling to appear to offer the slightest injury to M. du Fay, to whom electricity is unquestionably under great obligations, and whose writings evince a most honourable degree of regard to equity and candour; but that we may further strengthen the position we have taken up, we will quote M. du Fay's own passage on the subject of two electricities, and then give an extract from the history of Dr. Priestley, who was a contemporary of Mr. Symmer, and having been hostile to his theory, may therefore fairly be considered good evidence upon this subject.

"Chance has thrown in my way another principle, more universal and remarkable than the preceding one, and which casts a new light upon the subject of electricity. This principle is, that there are two distinct electricities, very different from one another; one of which I call *vitreous electricity*, and the other *resinous electricity*. The first is that of glass, &c. the second is that of amber, copal, &c. The characteristic of these two electricities is, that a body of the vitreous electricity, for example, repels all such as are of the same electricity; and, on the contrary, attracts all those of the resinous electricity." Du Fay, *Phil. Trans.* vol. xxxviii. p. 264.

"It had hitherto been universally supposed that all the phenomena of electricity were produced by the action of one electric fluid. Even M. du Fay, at the time that he imagined that he had discovered another electric fluid, distinct from that of glass, and peculiar to resin, &c. thought however that it was quite independent of the other, and that their operations were never combined. Dr. Watson and Dr. Franklin thought it was very evident that the difference between the two electricities, consisted in the one being a redundancy and the other a deficiency of the same matter. And all the experiments that had been made concerning the two electricities seemed to confirm this hypothesis. At length, however, Mr. Symmer produces a great number of curious experiments relating to the subject, and infers from them the probable existence of two electric fluids, *not independent*, but always coexistent, and counteracting one another." Priestley's *History of Electricity*, p. 267.

Wilcke, 1757.

Mr. Wilcke's *Disputatio Physica experimentalis de Electricitatibus*, published at Rostock, in 1757, added to the stock of electrical knowledge an entirely new branch of investigation; in fact, pointed out a new source of electrical excitation. This he produced by melting the resinous and other non-conducting bodies, and suffering them to cool spontaneously. If sulphur were melted in an earthen vessel, and suffered to cool, standing upon a conducting body, the sulphur after cooling exhibited strong electricity; but if the vessel had been placed upon glass, or any non-conductor, no effect was produced. Melted sulphur poured into a glass vessel becomes highly electrical in cooling, whether the glass stands upon conductors or not, the glass itself also exhibiting the opposite electricity. These facts also we shall more fully enter upon hereafter. Wilcke also appears to have discovered that, under a variation of circumstances, the same substance might be made to exhibit either of the electricities; and he gives a table of bodies, arranged in order, so as to show by the friction of any two together, which will exhibit the positive and the negative electricity. It is clear that he was unacquainted with Canton's researches on the same point, for he states that glass is positive with whatever substance it be rubbed.

Æpinus, 1759.

From the researches of Mr. Wilcke, we proceed to those of Æpinus, whom we have already incidentally mentioned; a name justly celebrated in the annals of electrical science. He first repeated the experiments of Mr. Wilcke on spontaneous electricity, and subsequently meeting with that philosopher at Berlin, they pursued their discoveries in concert. Of these the most interesting, both in progress and result, relate to the electricity induced or developed in bodies by bringing them within what has been called the electrical atmosphere of other excited electrics. One of their most curious attempts was to electrify two surfaces of a plate of air, so as to obtain a shock from the discharge of these surfaces, exactly on the principle of the Leyden jar. In this they perfectly succeeded, and thence made the obvious inference, that a cloud and the earth might similarly form the conducting substances for electrifying a plate of air contained between them, the discharge of which would produce the clap of thunder, and the flash of ordinary lightning. The name of Æpinus is however rendered much more famous by his ingenious and profound mathematical speculations, by which he was enabled to demonstrate and explain every known electrical phenomenon. Of the first causes in these wonders he was ignorant, and we are scarcely more wise; but the laws to which he reduced all cases of electrical excitation, afforded a beautiful specimen of philosophical generalization, founded upon Franklin's theory of plus and minus electricity. The title of this curious treatise is *Tentamen theoriæ Electricitatis et Magnetismi*; it was first published at St. Petersburg, in 1759.

Priestley, 1767.

In 1767, Dr. Priestley published his *History of the present state of Electricity*, with original experiments; a work accurately describing the progress of the science up to that period. His experiments, though numerous, did not bring forward any very important discovery, but are far from being uninteresting. He ascertained that charcoal was an excellent conductor, and that electrical discharges take place more readily and more completely through a short conductor than through a long one of the same diameter and the same substance. Two years afterwards, Priestley published his *Introduction to Electricity*, and in the following year *Additions to the History of Electricity*. The most interesting of his researches are detailed also in the *Phil. Trans.* of this time.

Caven 1770.

Passing over another *Introduction to Electricity*, by Mr. James Ferguson, which contained little of novelty, we arrive at the researches of that acute philosopher the Hon. Henry Cavendish. His first and most elaborate electrical paper is published in vol. lxi. of the *Phil. Trans.* It appears that he had formed the design of attempting to reduce all the phenomena of electrical attraction and repulsion to rigid mathematical investigation, and that he had completed his task before he was made acquainted with the labours of Æpinus on the same subject. On examining the *Tentamen*, of this latter electrician, he found that he had been anticipated; but as Mr. Cavendish's memoir was actually prepared to be submitted to the Royal Society, and as he considered that as his theoretical views differed somewhat from Æpinus, and his calculations were more rigid, he determined not to suppress the paper he had thus prepared for publication. In these calculations he, like Æpinus, proceeds upon the hypothesis of one electrical fluid. Previous to this time several curious observations had been published by Walsh, Hunter, and others, on the benumbing power of the torpedo, which had been justly considered to be due to electricity; and in 1776, Mr. Cavendish described in the *Phil. Trans.* an artificial torpedo, which he had made, and with which he was able to exhibit the ordinary properties of this singular fish. Some of the earliest electro-chemical experiments were also made by this admirable philosopher. He repeated the experiments of Warltire, forming water by the explosion of hydrogen with common air, and with oxygen: pursuing this subject, he obtained nitric acid by using electricity for determining the combination of oxygen and nitrogen.

Coul

If there be any one philosopher to whom electrical science is more indebted than to all others, it is M. Coulomb, to whose elaborate researches we shall hereafter have occasion again frequently to revert. The first step towards obtaining any true knowledge of the laws of electrical attraction and repulsion, was evidently to search for an accurate measure of minute forces estimated by their effects. This Coulomb obtained in what he called his Torsion balance. He found that if fine wires, of sufficient length to undergo no real disturbance of particles were twisted, the force with which they tended to untwist themselves, or to return to their first quiescent position, was exactly as the angle through which they had been twisted. In other words, that the force of torsion varies as the angle of torsion. Being able then to measure this angle with any required degree of accuracy, an exact comparative measure is obtained of any forces which can be made to operate in producing a torsion of the wire; and it is evident that electrical attraction is of this nature. Coulomb, however, made many successful applications of this instrument and principle to other branches of physical science. In electricity, he showed that the attractive or repulsive force varies as the inverse square of the distance. He ascertained the rate of dissipation of electricity, under various circumstances of atmospheric pressure and moisture. The dissipation also from imperfect insulators, and the modes of distribution of the fluid adhering to them. The mode or form of arrangement of *strata* of free electricity, arranged at the surfaces of bodies, and acted upon by the electricity of other bodies placed near to, or in contact with the former; with many other interesting problems of a similar nature, to be considered hereafter.

Volta. Considering, as we do, electricity and galvanism only modifications of the same natural phenomenon, we cannot pass over the electrical researches of Volta unnoticed, much as they are surpassed by the brilliancy of his discoveries in that distinct branch, which from him has been called voltaic electricity. In 1776, he discovered, or at least made known, the properties of the electrophorus; a sort of perpetual reservoir of electricity, and applied the principle of it to the construction of a condenser, an instrument for rendering visible very small portions of electricity.

Lavoisier and La Place, 1781. The order of time demands that we should next record the discoveries of MM. Lavoisier and La Place, on the electricity developed by the evaporation of fluids, and the solution of solids in acid menstrua. There is little doubt, and indeed some recent researches of M. Becquerell, in Paris, seem to prove that in all cases of chemical solution electricity is evolved. These experiments were made public in 1781. Volta published researches on the same subject in 1783, and M. de Saussure in 1786.

As the highly important results which many recent electricians have obtained, will form a considerable part of our statement of the present knowledge on this subject, we have need only to mention, with respect, the names of Cavallo, Nicholson, Van Marum, Cuthbertson, Henley, Read, Morgan, and Brooke. The Abbé Haüy, so well known by his laborious investigation of crystallographic mineralogy, made considerable additions to our knowledge of the electrical properties of minerals. Coulomb had considered the distribution of electricity upon spherical bodies, and La Place. M. le Comte la Place has subsequently investigated the same problem, with reference to ellipsoids of revolution. Biot. M. Biot also published the formula for spheroids differing but little from the figure of a sphere. In addition to the labours of these celebrated Poisson. mathematicians, M. Poisson has recently applied himself to researches of a similar nature. He investigated this distribution of the body of fluid around spheres in contact, and also at a distance from each other. The solution of the problems, which these and analogous cases have produced, forms some of the most intricate and elaborate investigations which physical science has ever presented to the mathematician.

In this outline of the history of electricity, we have purposely omitted all mention of that extraordinary discovery of Galvani, which contained the germ of a vast and fertile branch of electrical science. From the year 1790, in which Galvani first noticed the muscular contractions of animals by the contact of metals, and Volta, by his acute investigations, created as it were a new science, only about thirty years have elapsed; but in this time such a body of facts has been accumulated, and such a chain of important consequences has been deduced from them, as to claim a special place in our system of physical science. At present, although it certainly is the prevailing opinion that electricity and galvanism are but modifications of the same agent; yet both the facts made known by experiment, and the theories deduced from them have so few points in common, that it is expedient to treat electricity and galvanism almost as two distinct subjects. Connecting links appear to exist between every branch of physical science; and as electricity and galvanism are now clearly proved to exert an overruling power in magnetic phenomena; and it is exceedingly probable that the secret agency of the former may be traced in every operation of the latter, it would be rash to advance any absolute classification of these sciences as the fixed order of nature. All that we presume to act upon is this, that certain phenomena, which have long borne the name of *electrical*, will be treated of under the same grand division; that another such division will be occupied by a class of phenomena analogous to electricity, but to which usage has appropriated the name of *Galvanism*. And the effects of both these nominal agents upon another series of classified phenomena, designated *Magnetism*, being known and measured as pure magnetic effects have been considered under the Treatise bearing that title.

PART I.

PRACTICAL ELECTRICITY

INTRODUCTION.

WHATEVER may be the theoretical suppositions adopted concerning the primary cause of electrical excitation, whether we consider it a distinct fluid resident in bodies, and possessed of certain properties, or only as a peculiar affection of the molecules of matter, we shall here treat solely of its effects. We shall consider it purely a science of experiment, and the first part of our article will consist of a classification of facts, either accidentally noticed, or studiously developed by the ingenious researches of philosophers; while in the second part we propose to give such an outline, as the nature and limits of our undertaking may permit, of those physico-mathematical laws, from which the effects of electrical action seem to receive the most complete and satisfactory elucidation. This exclusion of all theoretical speculation upon the *origin* of electricity, must not be understood to extend to those hypotheses which have been framed for the purpose of binding together the scattered links of our chain of facts. Hypotheses like those of Du Fay, Symmer, or Franklin, may sometimes bear the name of theories also, but they are theories of a different order from those which would attempt to explain the primary cause of gravity, heat, magnetism, or electricity, and are in fact only efforts to bring all the observed phenomena under one general law of action. It will be observed that we constantly have to speak of "the electric fluid," but let it be understood that this is only a term made use of for convenience of expression. We know not whether such a fluid exists; and all that we mean by the phrase is, that the effect we observe is similar to that which would take place on the supposition of a fluid subject to certain laws of action, assigned to it by actual experiment.

Definitions. (1.) The earliest observed phenomenon may serve for an example of what we consider electrical effects. Let a piece of amber, sealing-wax, or smooth glass be smartly rubbed upon the sleeve of a coat, or any other dry woollen substance, and it will be found to have acquired the property of attracting to itself bits of straw, paper, fragments of gold-leaf, or any small and light bodies. The amber is then said to be *excited*, and the attractive power thus developed is called *electric attraction*.

Attraction. (2.) Next, let a small ball of cork, or what is still better, of dry elder pith, be freely suspended from a dry silken thread, the ball being about as large as a pea, and the thread a foot long. Take a glass tube of considerable size, and after it has been well rubbed with a dry silk handkerchief, present it to the pith ball, and an attraction similar to that already described will be produced, the ball approaching and adhering to the tube. After these bodies have remained a few seconds in contact, the ball will separate, or may easily be shaken from the tube. If now the glass be again brought towards the ball, instead of the attraction at first exhibited, the ball will recede, and avoid the tube. Here then is (in effect) *repulsion*. Let the pith ball now be touched with the finger, or a metallic rod for a few seconds, and upon the removal of this touching body, a repetition of the two original phenomena may be obtained. If instead of the glass tube, a stick of sealing-wax be employed, the same series of effects, viz. attraction and repulsion, may be produced, and in the same consecutive order as before. Here, as in the case of the amber, the glass or the wax is excited, its electric property is called into activity, and, as may be proved by experiment, is distributed upon the excited part of the surface of the body. The pith ball by the contact receives a portion of electric fluid thus set at liberty, and as it afterwards recedes from the originally excited body, it is clear that either the pith ball in its new state, or the fluid which it has received, is in some way or other repelled by the fluid remaining upon the glass tube, or stick of wax.

Repu

Oppo electr (3.) Let us now combine the effects of these two simple pieces of apparatus. Excite the glass tube as before, and communicate electricity to the pith ball, so that the two bodies may become repulsive of each other. While things are in this state, the pith ball remaining electrified, excite the stick of wax, and bring it near to the ball; instead of repulsion, a manifest attraction now exists between the wax and the ball. Conversely, if the pith ball be first touched by the wax, until repulsion be produced, and if then the excited glass be brought near to it, attraction again takes place. Obviously then the effects produced by the friction of the same substance upon glass and wax are of a nature directly opposite to each other; and hence it is evident, that there are either two states of the same electric fluid, or that there are two distinct electric fluids, having properties dissimilar, although the laws of action in each individual fluid may be the same. Hence arise the terms *vitreous* and *resinous*, to designate these different electrical states or properties. The law according to which these attractions and repulsions are manifested, will form the subject of future consideration.

Cond prop (4.) It may have been remarked, that in the above experiment, a direction was given to touch the electrified ball with the finger or a metal rod; by this method the ball was reduced to its natural state, that is to say, its electricity was conveyed away. Now had a glass rod been made use of, it would have been found inefficient, and the ball would have remained in its electrified state. Here then is a palpable distinction between metal and glass; the former is capable of conveying away electricity, the latter is not; the former then is termed a *conductor*, the latter a *non-conductor;* thus two general divisions are formed, under one or other of which, with certain limitations, all bodies may be arranged. It was formerly the supposition that these two classes of substances might also be called *non-electrics* and *electrics;* the former name indicating an incapacity for electrical excitation, and the latter marking the contrary property. This, as we shall hereafter show, is inaccurate, and the terms will consequently fall into disuse.

Light. There is one other electrical property, which may be exhibited by methods equally simple with those we have already noticed. If the glass tube before-mentioned be excited by a brisk friction, the experiment being made in a dark room, slight flashes of light will be perceived upon its surface. Perhaps, however, a more easy mode of exhibiting electrical light, is to take a long slip of coarse brown paper, well dried before the fire, and, while it is yet warm, let it be drawn quickly between the body and the left arm, holding it fast between the thumb and finger of the right hand, if it be immediately drawn along near to the surface of any metallic body, small sparks and flashes of light will be apparent in the dark, and a crackling noise will be heard.

Such is a very faint outline of the phenomena of electricity, given for the purpose of explaining the terms made use of, which, as ought to be the case with all descriptive designations in any science, are applicable to every possible case of electrical excitation. For example's sake, friction has been selected as the means employed for the developement of electricity; but, as will be hereafter pointed out, there are ten or eleven methods at present known, partly natural and partly artificial, by which electrical energies are produced. In some cases of effects decidedly electrical, it is very problematical whether the operating causes are simply electric, or are due to that modification which has been termed galvanism, such are De Luc's column, and the contact of dissimilar metals. We have before acknowledged our belief that all these singularities are but modified effects of one primary cause, an opinion which has now gained considerable currency in the scientific world, and is strongly supported by the beautiful experiments of Dr. Wollaston.

For the purpose of conveniently separating the doctrines of *free* and *induced* electricity from each other the following arrangement has been adopted, in which the three first chapters apply to the former department of our subject only.

Chap. I. Electrical phenomena developed by the common machine, with the construction of other apparatus of the same nature.

Chap. II. Instruments for indicating the presence, and measuring the intensity of free electricity.

Chap. III. On the spontaneous motions of the electric fluid.

Chap. IV. On the nature of electrical induction, and on the hypotheses of Du Fay, Symmer, and Franklin.

Chap. V. Application of the principles of induction to the artificial increase or quantitative accumulation of electricity.

Chap. VI. Effects of electricity upon organic and inorganic matter, and also upon the other imponderable physical agents.

Chap. VII. On the various sources of electrical excitation, and on the peculiarities attendant upon its developement, from each of these sources.

CHAPTER I.

Electrical phenomena developed by the common machine, with the construction of other apparatus of the same nature.

(5.) In the preceding introductory matter, we have endeavoured to render the ordinary terms employed in this science familiar to the reader, and we now design to enter upon the construction of an electrical machine, selecting, from the many that have been proposed, one of the most common and most useful. With this instrument, or of course with any other of tolerable construction, all the ordinary experiments which exhibit the peculiarities of electrical excitation may be performed; and, at the conclusion of this chapter, a few more of the best or most curious forms for the arrangement of an electrical apparatus will be noticed.

Cylinder machine. In fig. 1, A B is a hollow glass cylinder, supported at the two ends, in the direction of its axis, as the plate represents, and capable of a rotary motion upon that axis, communicated to it by means of a small wheel C, which is itself put in motion by a cord or catgut from a larger wheel D, turned by a common handle. F is a cushion of silk or soft leather, stuffed with hair, and supported by a glass insulating stand, L. By means of a screw at G, this stand may be fixed farther from or nearer to the cylinder, as a rough adjustment, to regulate the pressure of the cushion upon the cylinder; but in the most complete machines this purpose is effected by a spring placed at the back of the rubber, and capable of regulation, by a screw with a large spherical head, as seen in the plate. From the upper edge of the rubber there proceeds a flap of silk, or of silk varnished, extending over the cylinder to within about half an inch of the row of points, protruding from the prime conductor. K is a brass chain hanging loosely from the knob connected with the cushion, and communicating with the earth. H is the prime conductor, made of thin brass, having spherical caps at its extremities, and supported upon a strong glass pillar I, fixed into a circular wooden stand. At that end of the conductor which is nearest to the cylinder a row of points is inserted, having each end of the transverse wire from which these points project terminated by a varnished wooden ball, in order to guard against the accidental dispersion of electricity. These points extend to within about half an inch of the surface of the cylinder. The pivots upon which the cylinder is supported at each end are fastened into brass caps, which close two large orifices, one at each end of the cylinder, by means of which the interior surface of the glass is made perfectly clean and dry before it is mounted; and a sufficient bed of some resinous cement is melted into each cap, on the inside, so that no communication can take place between the external air and that within the cylinder. As the electricity is developed at that part of the cylinder which is applied to the cushion, a portion of each end of the glass, near to the vertical pillars of the supporting frame, is covered with a varnish of gum-lac, the more effectually to prevent the transmission of any portion of the electric fluid from the cylinder to the metal caps, and thence to the ground, through the frame of the machine.

(6.) Now let us suppose the wheel D to be set in motion by its handle, in the direction which the arrow points out; it is obvious that the smaller wheel C and the cylinder will move in the opposite direction. By the friction of the glass against the cushion electricity is excited, and this effect is greatly assisted by the application of an amalgam to the surface of the cushion. The electric fluid thus evolved is confined to the surface of the cylinder by the oil-silk flap; and at the point where that terminates it appears to be eagerly absorbed by the metal points attached to the prime conductor. In part we may suppose there is an actual transmission of electricity from the edge of the oil-silk; and in part we must attribute the charge received by the prime conductor to another species of action which we shall be better enabled to explain in a future part of this article. The sharp form of these points is, as we shall hereafter find, of all others the best adapted for the reception of electricity. Thus the prime conductor, which being of metal allows of the free transmission of the fluid, becomes strongly electrified throughout, and affords a convenient reservoir from which the fluid may be readily abstracted for all purposes of experiment.

(7.) We have already seen that there are two states, or perhaps kinds, of electricity; that which the machine now described communicated to the conductor is invariably produced by friction upon smooth glass, and is therefore termed vitreous electricity; but, in a future chapter, devoted to the peculiarities of friction variously applied, and to substances differing in their nature, it will be seen that this effect is subject to numerous modifications. It has also been proved, that whenever one electricity is developed, the other also is simultaneously produced; and in the machine before us, whatever vitreous (positive) electricity is delivered to the conductor from the glass cylinder, an equal quantity of the opposite kind, the resinous (negative) electricity, is manifested at the rubber; hence, if another conductor be made to communicate with the rubber, it becomes also charged and is called the resinous conductor. An excellent machine upon this principle, by Mr. Nairne, will be hereafter described; but, for a reason which we are unable at present to enter upon, whenever the vitreous conductor is to be plentifully charged, it is necessary that the rubber should be made to communicate with the great reservoir of electricity, the earth, which explains the occasion of the chain seen at K; and, conversely, if it be required to obtain a charge of resinous electricity from the cushion, the chain is removed, and affixed to the opposite conductor, forming also a communication with the earth.

Insu

(8.) Some other points of detail connected with the working of an electrical machine, may require a few words of explanation. Much depends upon the perfect insulation produced by the glass parts of the apparatus, and in this matter the great enemy to be guarded against is moisture. The working of even the best machine is decidedly superior in dry or frosty weather, to what it is when the air is loaded with aqueous vapour; and as glass is very apt to effect the condensation of moisture upon its surface, which greatly impairs its insulating property, it is usual to apply to some parts of the stands and cylinder a coat of some resinous varnish, by which this effect is in some degree obviated. For this purpose a varnish, made by dissolving sealing-wax in spirits of wine, is frequently employed; but it is much better, if possible, to apply the wax at once, by heating the surface which is to be coated. As gum-lac is a better insulator than sealing-wax, delicate varnishes formed from this substance are found to be peculiarly efficacious.

In all seasons, electrical experiments should be performed in a warm and dry room; and when a machine has remained long in disuse, it is usual to place every part of it at a convenient distance from a fire, in order that the moisture it may have received may be dissipated, and the machine brought more rapidly into action.

Ceme

(9.) In fixing the glass stands into their sockets, and for many similar electrical purposes, a strong cement is required, which may be softened by a gentle heat, and applied with the greatest convenience. One, which is found to answer exceedingly well, is made by melting together five pounds of resin, one pound of bees-wax, one pound of red ochre, and two tablespoons full of plaster of Paris. The two last ingredients are to be well dried and gradually mixed with the wax and resin while in fusion. (Singer.)

Ama

(10.) From the first amalgam, introduced by Canton, (which consisted of mercury and tin, in the proportion of two parts of the former to one of the latter, with the addition of a little chalk,) to the present time, numerous other compositions of a similar nature have been proposed. The following is certainly a very good one, and was recommended by the late Mr. Singer. "Melt together two ounces of zinc with one of tin, and while this compound is in a fluid state, let it be mixed with six ounces of mercury, and then let the whole be shaken in an iron or thick wooden box till cold. It is then to be reduced to a very fine powder in a mortar, and mixed with sufficient lard to form a paste."

actical. ctricity. In the application of the amalgam, it should be spread evenly upon the surface of the cushion, so as to meet the under edge of the silk flap, which is joined to the upper edge of the cushion, but is not to extend over any part of the varnished silk. From time to time it is found necessary to wipe the surface of the cushion, the flap, and the cylinder; for a part of the electrical effect of the cylinder is to attract dust, which the cushion wipes off; an accumulation of dirt rapidly takes place, and black specks and lines are seen fixed upon the surface of the cylinder. These may very easily be removed, by a rag moistened with spirits of wine. It is also convenient to have a piece of smooth leather, about five inches square, covered with amalgam, by the application of which to the cylinder with one hand, while the machine is in motion, a powerful degree of excitement is rapidly produced.

The substance of Mr. Nicholson's directions, for bringing a machine into good action, consists in, first, cleaning the cylinder from spots, by a little spirit of wine upon a rag; second, wiping all dust from the silk flap. To work the cylinder against a leather, with some tallow upon it, until the glass becomes dim; and lastly, to work the cylinder a short time, applying the amalgam from a leather upon the hand, as before directed. (*Philosophical Transactions*, 1789.)

Rubber. (11.) To Professor Winkler, of Leipzic, we are indebted for the introduction of the cushion instead of the human hand, which had been employed by all former experimentalists. Several variations have been made in the mode of fixing this important part of the apparatus, but we limit ourselves to a delineation of the spring cushion as now frequently applied to the best machines. It is represented in fig. 2, and differs from the plain cushion only by having a space of half an inch, interposed between the cushion itself and its wooden back. Within this space, there is a bent steel spring, by means of which a proper degree of pressure is maintained upon the surface of the cylinder, but which allows the cushion to recede, should this pressure be increased to such an extent as to endanger the safety of the cylinder. In the old machines, the same effect was produced, by various methods of adjusting the distance of the pillar bearing the cushion, generally by means of a screw fixed to some part of the frame. On rubbers, consult also Wolf, *Nicholson's Journal*, 1804.

(12.) It is by no means a matter of certainty what kind of glass is best adapted for the formation of cylinders for electrical purposes; they are at present principally made of flint glass, and as thin as possible to allow of sufficient strength. In choosing a cylinder, it ought to be free from knots and veins, and as nearly cylindrical as possible, in order that the pressure given by the cushion may be equable throughout the whole of its revolution. It is not uncommon for school-boys to make very tolerable little electrical machines of a glass jar, or even of a common green glass quart bottle.

Inside coating. It has been proposed to coat the inside of cylinders with a resinous cement; but this is now seldom done, although it would doubtless sometimes improve the action of a bad cylinder. The process is simply to melt together four parts of Venice turpentine, one part of resin, and one of bees-wax, and to boil the whole for about two hours, in an earthen pipkin, over a gentle fire. The cylinder is to be carefully heated, and a portion of the liquid cement poured in; then, by turning the cylinder about while the cement remains fluid, a sufficient coating may be applied to every part of its interior surface.

Prime conductor. (13.) Various substances have been proposed for the construction of the prime conductor, but the only essential condition to be fulfilled, is that it may have a metallic surface at the exterior. A solid metal conductor can contain no more electricity than one that has the same superficial extent and form, however thin it may be; for it will be hereafter shown, that all the electric fluid disposed in a conducting body resides within the body but indefinitely near to its surface. In general the prime conductor is cylindrical, having hemispherical ends; but if the diameter of this cylinder be small, it becomes necessary that the two extremities should be formed of portions of spheres of considerable magnitude, to prevent the spontaneous dispersion of the electric fluid. Conductors formed of thin copper or brass are the best, because they are little liable to injury, and may be made perfectly free from all asperities; but cylinders of wood or pasteboard, coated with tin-foil, or gold-leaf, if clean and in good repair, are found to answer very well. There should be, in different parts of the prime conductor, small round holes about the size of a goose-quill, into which balls, or points, or other pieces of apparatus may be inserted. The end nearest to the cylinder has a similar hole, for the insertion of the brass series of points seen in fig. 3. Secondary conductors, as they have been called, are but rarely employed in this country; their principal use would be in obtaining large sparks from a machine of slight power; but as a larger machine, capable of producing more electricity in a given time, may be almost as easily procured, we do not feel bound to enter very minutely into the details of their construction. They consist of one or more conductors, suspended by silk-cords from the ceiling of a room, all connected with each other, and with the prime conductor of the machine, thus affording a more extended surface over which the electricity developed by the cylinder may be dispersed, and from which it may readily be withdrawn for experimental purposes.

The following instruments are also required for the performance of certain experiments, which we shall shortly proceed to describe.

Insulating stool. (14.) A stool with glass legs. The top is made of a piece of mahogany, or other strong hard wood, and should be baked, and then varnished. The legs may be six or eight inches long, formed of solid glass rods, fixed into holes on the under side of the stool by cement; and, for greater security in insulation, these legs should all be covered with a coat of some resinous varnish, fig. 4.

(15.) Brass rods, terminated by balls and points, fitting into the prime conductor, fig. 5 and 6. Similar balls and rods, fixed to insulating glass handles, fig. 8 and 9. A few pieces of brass chain, for making communications from one part of the apparatus to another. Small spheres of rush pith, elder pith, or cork, suspended by silken threads, and others by fine silver wires, or threads of hemp, which should be previously steeped in salt and water, and then dried.

(16.) We have already stated that there are two kinds of electricity, to which, for distinction, the terms vitreous and resinous are usually applied. Two bodies, A and B, similarly electrified, repel each other. Two bodies, A and B, dissimilarly electrified, attract each other; and one body, whether charged with the vitreous or resinous electricity, is attracted by another body, to which no charge of free electricity has been communicated. It may be well to illustrate these fundamental laws of electrical action by a very simple experiment. Provide a glass stem, fig. 10, about a foot long, having at the top a curved brass wire, with a small knob and hook at the end. From this hook let there be suspended a fine doubled silver wire, having a pith ball at each extremity, so that the wires may hang freely, and the balls be in contact. Excite a stick of wax, by rubbing it upon dry flannel, and pass the surface of the wax along the bent part of the wire. By this operation a portion of the resinous electricity is communicated through the brass to the wire and the balls, and these, being similarly electrified, will manifest their mutual repulsion by the divergency of the threads.

Touch the brass part of the apparatus with the finger, so that all electrical charge may be removed, and repeat the experiment, only making use of a smooth glass tube instead of the wax, and repulsion will again take place between the balls, proving that when they are similarly electrified with vitreous electricity also, the same effect is produced.

Next, take two of these insulating stands, fig. 11, having a single wire and a single ball suspended from each. While they are standing at some distance from each other, communicate to the one vitreous and to the other resinous electricity, and then bring the two stands gradually near to each other, by moving either of them. The two balls will be seen to deviate from their position of vertical suspension, and to tend towards each other. Lastly, let the stands be separated, the tubes remaining charged, and bring near to either of them the large ball, fig. 7, holding the opposite end in the hand. The pith ball will tend towards the metal, and thus every case of the enunciation is easily and satisfactorily demonstrated. In the experiments here recited, we are limited to the supposition that the balls are formed of elder pith, or some conducting substance, otherwise electricity could not be transmitted to them through the supporting wires. The same proposition is however perfectly true of all bodies, whether conductors or non-conductors; but of course it is more difficult to induce, either by communication or by excitation, a charge of free electricity upon a ball of non-conducting matter, for the purpose of making this experiment.

Agency of the atmosphere.

(17.) It may have been remarked, that we frequently make use of the terms attraction and repulsion, but let us here pause, and inquire strictly what it is we mean by those terms. What is attracted? What is repelled? Experiment teaches us that all bodies upon which free electricity is disposed have a tendency to move either to or from each other. But by what mechanism is this effect produced? Is the force causing these motions dependent upon the immediate mutual action of the electric fluids, or must we take into consideration the intermediate agency of some third body?

To obtain an answer to these questions, let us first review the state of our actual knowledge of facts bearing upon this point. It has been proved that electricity has no peculiar affinities by which its molecules attract at a distance different substances with different degrees of force. It is extremely probable that the pressure of the air is the *principal* force which detains the electric fluid within an excited body; for if an electrified conducting body be placed under an exhausted receiver, the electricity is no longer retained, but rapidly escapes from the body as the exhaustion proceeds. An excited non-conductor also, under the same circumstances, soon parts with its electricity, but the process does not go on with such rapidity as in the case of the conductor. We may then fairly suppose that the air alone acting as a stratum of non-conducting matter, confines the electricity within a conducting body; although, from the freedom of motion which the molecules of the fluid possess within that substance, they may arrange themselves in forms dependent upon the forces that act upon them from without; and upon the diminution of the pressure of that insulating envelope, the air, may spontaneously remove to other bodies acting upon them according to the ordinary laws. A non-conducting body is found not to lose its electricity with such rapidity as a conductor does, supposing both to be placed in vacuo. The electric fluid can traverse all the interior substance of the latter body with inconceivable rapidity; but its molecules seem to have no power of moving among the particles of matter of the former kind. There is then some kind of a force attendant upon non-conducting power, which, as it enables the particles of matter possessing this property to detain in some degree the electric molecule, may of course, if means be found to set the electric molecule in motion, communicate motion to the particles of the non-conducting matter also. Perhaps therefore we may conceive two forces tending to detain the electric fluid upon a non-conducting body; one, the ordinary and acknowledged pressure of the air, and another, though less powerful one, either accompanying or arising from the non-conducting power itself. It has been proved also, by accurate experiment, that the repulsive forces of molecules of the same electricity, and the attractive forces of molecules of the opposite electricities, vary according to the inverse square of the distances. Hence, the arrangement that the electric fluid will assume upon any excited conductor may be calculated. It follows also, from theoretical considerations, that the reaction upon the surrounding atmosphere exerted by strata of the electric fluid varies as the squares of the thicknesses of these strata.

Let us now proceed to apply the action of these forces to account for the observed attraction and repulsion of electrified bodies. For the sake of convenience, we may trace these effects upon spherical bodies; but it is obvious that whatsoever is true of masses of matter in that form, will be true in *quality*, of matter arranged in any other form, although the laws we shall hereafter mention may produce some variation upon the *quantity* of that effect.

Adopting in part an illustration from M. Biot, we may consider the conditions of two electrified spheres A and B, considering the former fixed and the latter movable; for whatsoever is proved on this supposition will be true also in quality, if both the rical tricity.

bodies have freedom of motion. Three cases present themselves.

1. A and B, both non-conductors.
2. A, a non-conductor; B, a conductor.
3. A, a conductor; B, a conductor.

In the first case, the electrical molecules being fixed upon the non-conducting matter, by certain forces to which we have alluded, the bodies themselves must partake of the motions communicated to the electrical molecules. Every molecule upon each of the balls will exert a repulsive force upon every other molecule upon the same ball; but the resultant of all these forces can produce no effect upon the motion of the centres of gravity of each sphere respectively. In the next place, we have the attraction or repulsion of the fluid upon one sphere towards the fluid upon the other sphere; and as the bodies are non-conductors, whatsoever order of distribution the fluid upon each sphere has at first received, the same order will be retained. Suppose that the electricities are equally disposed around the spheres respectively. In this case each sphere attracts or repels the other sphere, in the same manner as if all the electric mass were collected at its centre. The force then with which the fluid upon B is attracted or repelled towards the fluid upon A, is due to the joint action of the two fluids upon each other; and the motion which is thus impressed upon the fluid with which B is charged, must, for reasons already given, cause the body B to be either attracted towards or repelled from A, as the case may be.

In the second case, we may consider the molecules of the fluid upon B, when acted upon by the molecules of the fluid A, as arranging themselves within the body B, (in which they can move freely,) according to that law of attraction or repulsion to which they are subject. Let fig. 12 and 13 roughly represent this case, supposing the former to be sections of a conducting and a non-conducting sphere, charged with opposite electricities, and the latter to be sections of two similar spheres charged with the same electricities. It is evident, that in both these cases the space between the dotted lines, and the full lines marking the surfaces of the spheres, may roughly represent the sections of the strata of fluids arranged according to the conditions of the respective cases. With regard to the sphere B, since it is formed of conducting matter, we cannot suppose any such force uniting the electric molecules to the material particles, as to be capable of producing a motion in the latter; and the only effective force which we have to consider is, that which arises from the pressures of the air and the electric fluid upon each other. Whatsoever intensity of electrical charge may have been communicated to the spheres, the reaction of the electric molecules upon the air is proportional to the square of the thickness of the electrical stratum at different points. In fig. 12, since the thickness of the electrical stratum is by the arrangement of the fluid much greater on the side O of the sphere than on the side M; the sum of the squares of all the lines drawn in the direction of radii for measuring the thickness of the stratum, is much greater on the side O of the sphere than on the side M of the same sphere; and therefore the reaction in the direction M O is greater than the reaction in the direction O M. Now the ordinary atmospheric pressures upon the sphere at the points M and O are equal, and in opposite directions; but, being unequally resisted, motion will ensue, and the sphere B will recede from the sphere A, as the arrow points out. By a similar course of reasoning, the sphere B, in fig. 13, will be shown to move in the opposite direction towards the dissimilarly electrified sphere A.

The consideration of the third case, proceeding upon similar principles, will lead us to results of the same kind; and, in fact, the third case becomes identical with the second, after the masses of fluid in each of the spheres have assumed those positions to which they are impelled by the mutual action of the molecules of fluid on one sphere, upon those of the fluid upon the other sphere. It is obvious also, that although in these supposed cases, for illustration, we have considered the sphere A as fixed, the same results in nature would have been obtained if both the spheres had been movable, only that the quantity of motion would then have been divided between the two bodies.

Should these illustrations meet the eye of the experienced electrician, it may be to him a matter of surprise, that the effects produced by the decomposition of the natural electricities of the bodies (when they are conductors) have not been here adverted to. The truth is, that as these effects do not diminish, but rather increase in all ordinary cases the actions here described, we omit for the present all the phenomena arising from induced electricity, in order that we may devote to that subject a portion of more undivided attention hereafter.

The explanation that has been given in the recent paragraphs of the mechanical agency of the air in producing many of the sensible effects of electrical attraction and repulsion, enables us to avoid the improbable supposition, that in their electrified state the particles of matter exert upon each other any new attractive or repulsive forces different from that with which they are endowed in their unelectrified state. It leaves to matter the power of being acted upon, but takes from it all active agency in these phenomena. As a proof that similar movements may be produced simply by the mechanical action of the air, without any real attraction or repulsion of material particles towards each other, M. Biot adduces the following elegant illustration.

Biot's illustration.

Let A B, fig. 14, represent a glass vessel filled with some heavy fluid, such as water, or mercury, suspended vertically from a fixed point, S. The vessel itself will remain motionless, and the fluid which it contains can produce no motion in an horizontal direction, because the lateral pressures at the same depth in opposite directions A B, B A are equal to each other. But suppose that by means of a burning mirror M, we direct a cone of light upon the point A, and thus make a small perforation in the side at that point. The fluid now escaping freely from this aperture, the pressure in the direction B A vanishes, and the pressure in the direction A B remaining constant, and being no longer counteracted, the vessel will move from the mirror as if it were repelled by it. Thus also a hole made in the opposite point B might produce an apparent attraction, although in neither case is there any real attraction or repulsion, but only an effect of simple hydrostatic pressure, depending upon the fluid contained in the vessel A B, and the surrounding atmosphere.

Whatever may be the nature of electrical attractions and repulsions, the effects produced are among the most subtle manifestations of physical force; for the interposition of glass, resins, and non-conducting bodies does not destroy these effects. An excited stick of wax, suspended in a glass flask or tube, will still attract light bodies to the surface of the glass. This appearance might however be accounted for on the principles of induction, without supposing the glass to be permeable to the direct influence of electricity.

(18.) Being now in possession of the electrical machine, and in some degree prepared to comprehend the principles upon which the experiments performed with it depend, we shall select a few of the most interesting of these experiments, from the countless numbers already published, as further illustrations of the objects to which this chapter has been specifically devoted.

Experiments depending upon electrical attraction and repulsion.

Experiments.

(19.) *Exp.* Remove the prime conductor from an electrical machine; let the cylinder be put in motion by turning it with one hand, while the back of the other hand is brought near to that part of the cylinder which is just beneath the termination of the silk flap. A singular sensation is perceived, something like that which is produced by touching a cobweb. The cause of this sensation is to be sought for, partly in the ordinary attraction exerted upon the fine hair covering the surface of the skin, but principally in the actual accumulation and progress of resinous electricity towards the vitreous electricity excited by the cylinder of glass.

(20.) *Exp.* Adjust the prime conductor to the machine, so that the row of points may be as near to the cylinder as possible without touching it. Let the conductor be electrified by putting the machine in motion; and then, holding a linen or silver thread by one end, bring the pith ball, attached to the other end, near to the excited conductor. The ball will be immediately attracted, and will continue to adhere to the conductor as long as any electricity shall remain in it. In this case the ball continues to absorb electricity from the conductor, but as this electricity is conveyed away by the thread to the hand of the person holding it, and so to the earth, as fast as the ball can receive it, the effect continues as long as a fresh supply of the fluid can be found in the conductor to produce a continued repetition of the attraction originally exhibited. Let the same experiment be repeated, varying it only by making use of a ball attached to a dry silken thread. In this case attraction will be manifested at first as before; but as soon as the ball has obtained from the conductor such a portion of electricity as it is capable of receiving, repulsion will take place; and the ball, hanging freely by the silk, cannot be made again to touch the conductor, until the electric charge, which it has received, be removed by the contact of some conducting body, or until the electricity of the conductor itself has been removed, in which case the ball will be again attracted in order that the two bodies may share the free electricity retained by the pith ball.

(21.) *Exp.* Take a similar ball, having its surface covered with gold-leaf, suspended also by a silken thread, and holding the silk in one hand, allow the ball to obtain a charge of electricity from the conductor until repulsion is produced. Then, with the other hand, bring the brass ball, fig. 7, near to the pith ball, but on the side opposite to that which is presented to the conductor. The gilded ball will be attracted to the brass knob, and after it has parted with its electricity, it is in a state again to be attracted by the conductor; and these effects will proceed alternately, so that the ball will oscillate between the conductor and the brass knob, as long as any free electricity remains upon the conductor.

(22.) *Exp.* Let a few pieces of thread, about a foot long, be tied together by a knot at each end, and having attached one end to the prime conductor, let the other end hang loosely in the air. Upon turning the machine, the threads become similarly electrified, and therefore repel each other, consequently, the central part of the fasciculus will swell out, like the meridians drawn upon a globe, and the lower knot will, of course, be elevated towards the conductor.

(23.) *Exp.* Insert one end of the pointed brass rod, fig. 5, into the conductor, and while the machine is in action, let the point of the rod be moved about over the inner surface of a dry glass tumbler. Place a number of small pith balls or fragments of paper rolled up into balls, upon a surface of tin-foil, or a metal plate, and reverse the tumbler over the balls. A violent system of attractions and repulsions immediately takes place, the balls jumping up and down alternately, between the glass and the metal, until all the electricity, which was disposed upon the surface of the glass, has been removed.

(24.) *Exp.* Suspend a disc of pasteboard or wood, coated with tin-foil from the prime conductor, by linen threads, and place underneath this disc a similar one communicating with the ground by a chain, and capable of being fixed at different distances from the former plate. Let a number of fragments of gold-leaf, or paper, or small painted figures, be placed upon the lower plate. These light bodies, upon putting the machine in motion, will be immediately attracted and repelled alternately between the two plates, and a sort of electrical dance is performed.

(25.) *Exp.* Fig. 15 represents an elegant experiment on the same principle, called the electrical bells. A glass stem is surmounted by a brass ball A, having two transverse bars, also of brass, from the extremities of which four chains support four small bells B, B, B, B. Upon the lower part of the glass rod, a fifth bell B is affixed, having a chain C to communicate with the earth. Four silken threads from the transverse bars serve to carry four small brass balls, which play between the four exterior bells and the central one. Upon a communication being made between the ball A, and the electrified conductor of a machine, the four brass balls strike the four outer bells, and the inner one, alternately; and thus the electricity is transmitted from the cap A to the outer bells, and thence carried by portions upon the balls to the inner bell, from whence it escapes to the earth.

(26.) *Exp.* Employing the pointed wire fig. 5, let a small piece of sealing-wax be affixed to one end of it, while the other end is inserted into the hole at the end of the prime conductor. Let the wax be softened by the flame of a candle, and then put the machine in motion. The melted wax becomes a conductor, and in consequence of the repulsion of its electrified particles, fine filaments of wax are thrown out from the melted mass, and may be collected in the form of a fine wool upon a paper held underneath.

(27.) *Exp.* Suspend a small metallic bucket filled with water from the prime conductor, and place in the water one end of a glass siphon, formed of a glass tube with a capillary bore, such that the water will scarcely drop from it. Upon turning the cylinder so as to convey electricity to the bucket, the water immediately flows in a stream; and if the electrical excitement be very powerful, the descending current will separate into several branches. (Boze, Nollet.)

(28.) *Exp.* Let a sponge saturated with water be suspended from the prime conductor of an electrical machine. The water will at first only drop gradually from the sponge, but when the conductor shall have become strongly electrified, the drops will fall plentifully, and in the dark produce the appearance of a luminous shower of rain.

Electrical light.

(29.) We have already more than once incidentally adverted to the phenomenon of light, as a frequent accompaniment of electrical excitation, and the present appears to us at least, a convenient opportunity for taking a general view of the circumstances which appear to influence its production.

It was the opinion of the early electricians, that the light which they observed, was the electric fluid itself, which became luminous at some certain degree of accumulation. The analogous fact, however, of common atmospheric air becoming luminous by violent compression, led M. Biot to the supposition that the electrical light also might be occasioned by the same mechanical process; in short, that it was caused by the powerful pressure exerted upon the air by the impact of electricity in its passage through that resisting medium. (*An. de Chimie*, tom. liii. p. 321.) The series of facts, and the judicious observations made upon them by this able philosopher, will form the substance of our present paragraph upon electrical light; for it is a singular circumstance that by far the greater part of the modern treatises upon electricity, which have appeared in this country, have issued from the pens of the makers of electrical apparatus, oi lecturers upon this science; and consequently, however valuable these works may be in some practical details, they appear rather deficient in clearness of arrangement and philosophical generalization.

Having premised, as a necessary caution, that experiments upon electrical light must, generally, be carried on in a dark room, we proceed to our task. If the sparks, which repeatedly pass between two electrified conducting bodies, be observed through a glass prism, the ordinary colours produced by the decomposition of light will be obtained, (Wollaston *Phil. Trans.* 1802;) but the prevailing tint of colour will vary according to the different substances through which the sparks pass, or from which they are abstracted. Additional confirmation is brought forward by the experiments of Dr. Brewster, in favour of the opinion that electrical light does not differ from ordinary light. This able experimentalist found that it is capable of undergoing polarization, either by transmission through a doubly refracting crystal, or by reflection at the proper polarizing angle, from a polished plane surface, or by oblique refraction through a pile of glass plates.

In atmospheric air, and under the ordinary pressure; when electricity passes by explosion from one metallic body in order to enter another metallic body, the light is white; but if we present a finger to an electrified conductor, the spark produced is violet. If one of the bodies concerned in the explosion be a green plant, or water, or ice, the light is red. Lastly, even between the same two metallic conductors, the colour may vary from the most brilliant white to the most delicate violet; according to the distance through which the electricity is transmitted, and according to the resistance of the medium which it is compelled to traverse.

To prove the former of these propositions; affix a metallic wire, terminating in a sharp point, to the extremity of the prime conductor of a machine, arranged for the production of vitreous electricity. Having set the machine in action, present towards the point of the wire one of the metal balls of fig. 7. When the surface of the sphere is near to the point, the transmission of electricity will take place in a continued succession of small sparks of brilliant whiteness, passing to the nearest part of the metal sphere. This whiteness will decrease and tend towards a red colour, as the striking distance of the bodies is gradually increased. The explosions will then no longer be directed towards one point upon the sphere, but will strike various points throughout a certain extent of its surface; and at last, at some greater distance, there will no longer be a sharp explosion, but a cone of feeble violet light will diverge from the extremity of the point, and will extend its base over the nearest half of the sphere. In this case, instead of the crackling which the sparks produced, we hear only a sort of continued hissing; the cone of light will gradually become more feeble as the distance increases, and at some distance of separation will altogether cease to be perceptible.

Such is the effect produced by an increased distance in a medium of which the density remains constant; but the same effect may be produced, the distance remaining invariable, by causing an alteration in the density of the medium. Take a glass vessel in the shape of an ellipsoid, fig. 16, pierced at the two extremities of its major axis for the reception of two metallic rods, each terminated by the half of a metal sphere. These wires are to pass through an air-tight plug, so that by sliding them up or down, they may be fixed in the interior of the vessel at any required distance from each other. Let one of the apertures be furnished with a stop-cock and screw, by which it may be fitted to the plate of an air pump. Having made the upper wire communicate with the prime conductor of a machine, while the lower one communicates with the earth, transmit the electrical current through the two rods, and adjust their two extremities so that the transmission may be effected by an almost continual succession of vivid sparks from one hemisphere to the other. In this case the light is white, as in the former experiment, when the sphere was sufficiently near to the point for the electricity to pass by explosion. But now let the density of the air within the receiver be gradually diminished, the transmission from one ball to the other will take place before the electricity shall have attained to the same degree of intensity upon the hemisphere. In this case the whiteness of the light is seen to diminish, and it gradually changes to a violet tint. Thus, in these two experiments, the progressive changes in the colour of the light are attendant upon the diminution of intensity in the electricity transmitted. The only difference in the two cases is, that in the former the diminution is occasioned by the increase of the distance, by which the communicated electricity is expanded throughout a greater space; while in the latter, of the rarefied air, the intensity of the electricity is weakened by the diminution of resistance in the medium, which allows of its escape through a given distance, at a lower degree of accumulation. According to this view, we might suppose that in different experiments, where the same degree of rarefaction is employed, the more intense the electricity transmitted, the whiter would be the light. And this is found to be the case, for if we make the discharge of a strong electrical battery pass through a small tube, exhausted as completely as is possible by the best air pump, the light produced by this highly accumulated electricity is of the most brilliant whiteness.

(30.) The luminous trace which electricity produces in passing through the air out of conducting bodies, varies also with their figure. When a spherical and uninsulated conductor is presented at a distance toward a fine point vitreously electrified, we have already seen that a luminous cone is formed, having its vertex at the extremity of the point. Should the sphere be removed, and the point remain in the air, the cone becomes changed into a small luminous brush or pencil of diverging rays. This pencil is much more beautiful and powerful if the point, instead of being extremely fine, is a little rounded at its extremity; so that a powerful condensation of electricity may take place, not only upon one minute point, but may extend over rather a larger surface, though with a somewhat diminished intensity. We have supposed the point to be vitreously electrified, but when resinous electricity is communicated to it, the pencil of light is no longer seen, but only a minute star of bright light.

M. Biot considers that it is at present impossible to account for these differences of appearance, but that it is probable that they depend upon the nature of the two electricities, and upon the manner in which they act upon the air in the circumstance of their transmission; particulars of which we are utterly ignorant. The advocates of Franklin's doctrine consider that these experiments upon electrical light, are favourable to the hypothesis of one electrical fluid, as we shall hereafter explain.

(31.) From all these researches, we learn that the intensity of the electrical light depends always upon the ratio existing between the quantity of electricity transmitted, and the resistance of the medium through which it has to pass. There can be no doubt but that at the instant of the explosion, this medium is struck, compressed, and suddenly driven back upon itself; also when it is elastic it undergoes a momentary expansion, which we may make apparent by a direct experiment. For this purpose we may employ what is called the electrical air thermometer of Kinnersley. In fig. 17, A B is a wide glass tube, having its ends closed by two air-tight caps A and B. Through these caps two wires, T, T, slide in the direction of the axis of the tube, terminated by brass balls, so that by regulating the distance between these two balls, a strong spark must be collected to pass through the interval of air between them. At the lower extremity there is adapted to an aperture in the cap another small tube, *t t*, bent at right angles, and through this tube a sufficient quantity of mercury is introduced, to fill the lower part of both the tubes. Having formed a communication between one wire T and the earth, and leaving the other wire to communicate with the prime conductor of an electrical machine in action, the electricity will pass by sparks from one wire to the other, and at each spark the air in the cylinder being dispersed by the repulsive force, presses upon the surface of the mercury, which is thus compelled to rise in the smaller tube, but descends again immediately after the explosion. This motion then demonstrates the separation produced between the particles of the mass of air through which the discharge takes place; and if we take into consideration the unmeasured and immense velocity of the motion of electricity, we shall plainly perceive that the particles of air, immediately exposed to its impact, ought, in the first instant, to undergo individually all the effect of compression. From that cause alone they ought to disengage light, the same as when they are subjected to any other mechanical compression. Thus one part at least of the electrical light is necessarily due to this cause, and there is, moreover, no experimental ground for supposing that any other cause assists in the production of this phenomenon.

Kinnersley's air thermometer.

It may possibly be adduced as an objection to this hypothesis, that the electrical light is produced in a vacuum. But let it be remembered, that what we inaccurately term a vacuum, is, in truth, only a space still containing some attenuated vapour or other. The barometric vacuum is filled with a mercurial atmosphere, and it seems impossible to obtain a space entirely devoid of some metallic vapour, even by those methods which have so long been supposed perfect in this respect. (Sir H. Davy, *Phil. Trans.* 1822.) By employing the very best air pump, although the rarefaction of air appears to us great, yet its pressure is not reduced to the thousandth part of what it was at first; and in the best possible barometric exhaustions, the apparent vacuum is never filled by the vapour of mercury only. A medium of this kind, though appearing to our ideas greatly attenuated, must offer some resistance, and oppose some degree of reaction to a velocity so great as that possessed by electricity. In such a case the widely separated molecules of which it consists, may be acted upon by an electrical discharge, tending to push them aside with a rapidity greater than they are able to accommodate. By this effect, they must undergo compression among themselves, with a disengagement of light and heat, but to a much less extent than would have taken place in a denser gas, exposed to the same discharge.

Should it be objected that electricity of great intensity is capable of producing a spark also under water, as may be proved by discharging a battery through conductors at a very small distance from each other immersed in water, the argument can not avail much; for in all water there is a portion of air, in the state of mechanical admixture, among its tical ricity. particles, by which the effect might in part be accounted for; but the water also has long been supposed, and has recently in this country been satisfactorily proved, to be a compressible fluid, which enables us to account for the phenomenon of electrical light on the hypothesis already advanced for that purpose.

Lastly, it may be asked, why should the electric light be violet when the electricity is feeble, and white when produced by a violent discharge. This variation in its tints still further explains its origin; for it may be seen also in combustible substances, according as the combustion is slow or rapid, that is to say, according as the oxygen which in that combustion is absorbed from the air, is condensed with greater or less rapidity. The light which sulphur disengages when it begins to burn is violet, also like that of feeble electricity; but the light of sulphur in vigorous combustion is white.

Upon a review of these arguments it appears, 1st, that electrical light is certainly produced, in part at least, by the mechanical compression of the air, the vapours, and, in general, the various constituents of the medium through which the passage of electricity is effected. 2ndly, That there is no analogy opposed to the supposition of all the light accompanying a discharge proceeding from that cause. 3rdly, And that no other cause is suggested or even indicated by the phenomena.

Experiments on electrical light.

peri- ents. (32.) Perhaps the most simple and not the least interesting experiments upon electrical light, depend upon its passage from one conducting body to another. *Exp.* Let a number of small circles of tin-foil be pasted in a spiral form round a glass tube, fig. 18, so that the discs may be about $\frac{1}{20}$th of an inch from each other. If this tube be held towards the prime conductor of an electrical machine in action, or in any other way placed in an electrical circuit, the simultaneous passage of the sparks from one disc to another, will produce a spiral line of light identical with the course of the tin-foil round the tube. In a similar manner any word or picture may be arranged upon a glass plate, so as to become illuminated by the transmission of electricity in the dark.

(33.) *Exp.* Place a lump of sugar in contact with the exterior coating of a charged jar; bring one of the balls of the discharger, fig. 82, into contact with the sugar, and let the other ball be extended so as to touch the knob of the jar; upon the passage of the discharge through the sugar, its whole mass will become beautifully illuminated, and will so continue for a second or two.

(34.) *Exp.* "Attach one wire to the outside coating of a charged jar, and another to one of the branches of the discharging rod; and having placed their other ends at the distance of $\frac{1}{10}$th of an inch, press the thumb upon the two ends. Bring the other branch of the discharging rod in contact with the knob of the jar, which being thus discharged, the spark will pass under the thumb, and illuminate it in such a manner, that the bone and the principal blood vessels may be readily observed." (Brewster.)

(35.) *Exp.* Let two pointed wires be inserted obliquely into a piece of soft deal, so that the points of the wires may be an inch distant from each other, and at different depths below the surface of the wood, in the direction of the longitudinal fibre. Upon passing a strong spark from one to the other, the wood will become illuminated, and the spark seen at different depths will appear under different variations of colour.

(36.) *Exp.* Let a short chain be laid upon a table, one end of the chain being in contact with the outside coating of a charged jar, and let another piece of chain be placed with its extremity within $\frac{1}{4}$th of an inch of the end of the first chain. Upon these two ends place a glass filled with water, and with the discharging rod form a communication between the latter chain and the knob of the jar. At the instant of the electrical discharge, the whole glass of water will become brilliantly illuminated.

(37.) *Exp.* "Insulate a large brass ball, and connect with it a silver thread of two or three yards long, the other extremity of which is held in the hand; when sparks are made to strike upon the brass ball, the whole of the thread will be rendered faintly luminous." (Singer.) The same experiment may be performed with a long continuous strip of gold-leaf about $\frac{1}{4}$th of an inch in width.

(38.) *Exp.* Let a glass cylinder, three feet long and three inches in diameter, be fitted with air-tight metal caps at each end; so arranged, that by a stop-cock and screw at one end, the cylinder may be fitted to the air pump for exhaustion. Let there be a sliding wire passing through the opposite end, carrying a circular brass disc within the cylinder, so that the disc may be placed at any required distance from the plate closing the opposite end of the cylinder. If now the upper end of the wire be made to communicate with the prime conductor of a machine, and the lower plate with the earth, the air being exhausted from the cylinder, a beautiful sheet of light will pass from the upper to the lower plate. This column of fire will be of more or less perfect continuity and regularity, in proportion to the degree of exhaustion produced within the cylinder by the action of the air pump. (Watson.)

(39.) *Exp.* Let the plates of the apparatus last described, be placed at the distance of about ten inches from each other, and through this interval discharge a common Leyden jar. The passage of the charge from one plate to another will, if the vacuum be good, produce one continuous and brilliant body of fire. (Watson.)

(40.) *Exp.* "Seal a short iron or platina wire within one extremity of a glass tube thirty inches long, so that the wire may project a little within its cavity, and screw a ball upon the exterior end of the wire; fill the tube with quicksilver, and invert it in a basin of the same, thus producing a Torricellian vacuum in the upper part of the tube. A spark, which in the open air would only pass through a quarter of an inch, will pervade six inches of this vacuum with facility; and if the quicksilver be connected with the ground, a current of faint light will pass through the upper part of the tube, whenever its ball is brought near to an electrified conductor. By passing up a drop of ether or water, an atmosphere of the vapour of either of these substances may be produced in the tube. In such a medium the current of electrical light assumes various colours, which vary with the density of the medium. In the vapour of ether, a spark viewed near is green, but at some distance it appears of a red colour. By this apparatus the spark may be examined in its passage through different gases. In hydrogen it appears faint and red, in carbonic acid gas it is white, as also in condensed air.

(41.) *Exp.* Present an insulated sheet of paper to the end of a vitreously electrified conductor at some small distance. A beautiful star of radiating light will be projected upon the paper. If the conductor be charged with resinous electricity, no star will appear, but a cone of rays will be seen, the vertex of which is at the conductor, and the base upon the plane of the paper.

Spark.

For numerous observations upon the electric spark, we are indebted to Messrs. Brooke, Nicholson, and other early electricians. It appears that in a medium of given resistance, such as the atmospheric air, the form of the spark varies with the forms of the conductors from which it is emitted, and by which it is received. Thus, if it be taken from a ball two or three inches in diameter, it will move in a straight line; but if a spark of the same power be taken from a ball half an inch in diameter, it will move in a zigzag direction through the air.

The absolute length of the spark seems to depend upon several circumstances, such as the form and magnitude of the conductors employed for its transmission, and the part of their surface from which it is received, also the intensity of the electricity communicated to them. Mr. Brooke constructed a singular conductor, formed of about twenty rods of wood seven feet in length and ¾ths of an inch in diameter, coated with tin-foil, and all connected together in the form of a gridiron. The power of giving sparks possessed by this instrument was by no means considerable. A longer spark may be obtained from a brass ball of two inches in diameter, affixed by a stem to the prime conductor, than from any part of the conductor itself. It is, however, unnecessary to multiply these observations, for every case of the kind may be clearly accounted for, and even foreseen from the principles of electrical distribution hereafter to be explained. It may, however, be interesting to exhibit by a few diagrams the differences observed in the appearances of sparks produced by the two opposite electricities. Fig. 19 represents the straight form of a spark passing from a ball A at the extremity of a resinously electrified conductor, to a ball B in its natural state. In fig. 20 the ball A is vitreous, and B in its natural state. In fig. 21 the ball A is resinous, and the ball B vitreous. Fig. 22, 23 and 24, represent conducting rods placed parallel to each other, under the following circumstances: In fig. 22 B is vitreously electrified, and A in its natural state connected with the earth. In fig. 23 A is electrified resinously, and B connected with the earth. In fig. 24 A is resinous, and B is vitreous; the form of the sparks produced in all these cases, will be seen by a simple inspection of the figures.

Having now arrived at the conclusion of those experiments, which may result from the direct action of the electrical machine, we proceed to describe, as far as our limits may permit, a few of the most recent improvements introduced into the mechanical construction of electrical apparatus.

Nairne's electrical machine.

Nairne's machine.

(42.) One other machine, acting by a glass cylinder, is all that we consider it of importance here to describe. Fig. 25 is a representation of this instrument, the parts of which are sufficiently obvious without any minute and detailed description. The peculiarity of this machine consists in its having two conductors placed parallel to the cylinder, the one A, connected with the rubber, for the reception of resinous electricity, and the other B, near to the termination of the oil-silk flap, for the reception of vitreous electricity. This instrument was made by Mr. Nairne, and for all purposes of experimental research, wherein sometimes one electricity is required, and sometimes the other, it is a most valuable piece of apparatus. If a communication be formed by a chain passing from one conductor to another, no permanent excitation is produced, as the vitreous and resinous electricities immediately reunite; and of course to obtain either electricity in considerable quantity from its appropriate conductor, the other conductor must have free communication with the earth.

Descriptions of several of the earlier cylinder and globe machines, may be seen in Priestley's *History of Electricity.*

In ho pl ch

(43.) The plate machine, wherein the excitation of electricity is produced by the friction of a large circular disc of glass instead of the cylinder, is said to have been invented by Ingenhouz, and certainly forms an elegant and valuable addition to our electrical apparatus.

Fig. 26 is a representation of this instrument in one of its most common forms, as first constructed by Mr. Cuthbertson; the arrangement and use of every part is too obvious, from a mere inspection of the plate, to require any more specific description.

The plate machines are, on the whole, perhaps, preferable to those constructed in the cylindrical form; but it was always a matter of great difficulty so to insulate the rubbers, as to obtain their resinous electricity if required. To effect this purpose, they have frequently been mounted upon glass feet, by which the whole machine may become insulated; but the elegant contrivance employed in the splendid instrument next to be noticed, has entirely obviated this inconvenience.

Te m

(44.) The celebrated machine constructed for the Teylerian Museum at Haerlem, under the direction of Dr. Van Marum, has produced some of the finest experiments with which electricity has yet been enriched. It forms an almost perfect model for the construction of similar apparatus; and as we have, by omitting the inferior instruments, obtained some space which may be devoted to more valuable matter, we feel that we cannot better dispose of some portion of this space than by a description of this magnificent instrument.

Fig. 27 "exhibits a perspective view of the machine. The cushions are each separately insulated upon pillars of glass, and are applied nearly in the direction of the horizontal diameter of the plate. The ball, diametrically opposite to the handle, is the prime conductor, and the semicircular piece with two cylindrical ends serves, in the position of the drawing, to receive the electricity from the plate. By the happy contrivance of altering the position of this semicircular branch from vertical to nearly horizontal, the cylindrical ends may be placed in contact with the cushions, and the prime conductor instantly exhibits negative electricity. But as it is necessary that the cushions should communicate with the ground when the positive power is wanted, and that they should be insulated when the negative power is required, there is another semicircular branch applied to the opposite side of the plate, nearly at right angles to the first. That is to say, when positive electricity is wanted, the second branch, denoted by I I in the section, fig. 28, is placed nearly horizontal, and forms a communication from the cushions to the ground, through a metallic rod from K, behind the mahogany pillar which supports the axis; but when on the contrary the negative power is wanted, and the branch from the prime conductor is placed in contact with the cushions, this other branch from the axis is put into the vertical situation, and carries off the electricity emitted from the plate of glass.

"The axis of the plate B *h*, fig. 28, is supported by a single column A, which for that purpose is provided with a bearing piece K, on which two brass collar pieces D D, represented more at large and in face at fig. 30, are fixed and carry the axis itself. The diameter of the glass plate is thirty-one English inches. The axis has a counterpoise O of lead to prevent too great friction in the collar D nearest the handle. The arc of the conductor E E, which carries the two small receiving conductors F F, is fixed to the axis G, which turns in the ball H. On the other side of the glass plate is seen the other arc I I of brass wire half an inch in diameter, fixed to the extremity of the bearing piece K, so that it may be turned in the same manner as the arc E E. The two receiving conductors F F, are six inches long, and two and a half inches in diameter. The double line P represents a copper tube terminating in a ball Q. It moves like a radius upon the stem R of the ball S, which being screwed into the conductor H, serves to confine the arm P in any position which may be required. The diameter of the ball S is only two inches, which, together with certain other less rounded parts of this apparatus, may serve to show that the considerable electricity from this machine is (in Mr. Nicholson's opinion) less disposed to escape than if it had proceeded from a cylinder. The dissipation of electricity along the glass supports, is prevented by a kind of cap T of mahogany, which affords an electrical well or cavity underneath; and likewise effectually covers the metallic caps into which the glass is cemented. The lower extremity of the cap is guarded in the same manner by a hollow piece or ring V of mahogany, which covers the metallic socket into which the glass is cemented. The three glass pillars are set in sliding pieces, as marked on the platform of fig. 27, which are nine inches long.

"The rubbers of this machine differ in no essential particular from those described by the inventor, in the *Journal de Physique* for February, 1791; and the apparatus for applying them is described in the same work for April, 1789. Fig. 29 represents a section of this judicious piece of mechanism seen from above. A metallic sliding piece *b b*, is slided into a correspondent face on the ball Z, which is one of those fixed on the top of the glass pillars, near the circumference of the glass plate in fig. 27. To this is affixed the piece *d d*, which terminates in two hinges *g g*, that allow the springs *e e* to move in the plane of the horizon. The pieces *g g* represent the woodwork of the cushions attached to the extremities of the springs by the hinges *h h*. The springs are regulated by the bolt and screw *i i*. The two cushions are thus made to apply to the plate equally through their whole length; the actions on the opposite sides of the plate are accurately the same, and the play of the hinges *g g* prevents the plate from being endangered by any strain in the direction of its axis. It is certain that before this adequate provision was made, to secure those essential requisites, it was impracticable to apply the cushions to a plate with the same safety and effect as to cylinders, which possess much strength from their figure.

"The inner extremities of the cushions are defended by the plates of gum-lac Y Y, which cover the three sides or edges, and prevent their attracting the electric matter from the ends of the receiving conductor.

"That part of the axis which moves between the collars is made of steel. The middle of the non-conducting part of the axis is a cylinder of walnut-tree wood *a a a a*, baked until its insulating power is equal to that of glass, and then soaked in amber varnish while the wood still remains hot. The two extremities of this cylinder, which are of a less diameter, are forced, by strong blows with a mallet, into the stout brass caps *b* and *c*, in which they are retained by three iron screws *d d*. The cylinder *a a*, and the brass caps, are covered with a layer of gum-lac *e e e e*, to preserve the insulating state of the wooden cylinder more perfectly, and to prevent the cap *b* from throwing flashes to the rubbers. The bottom of the cap *b*, is screwed home upon the tapped extremity of the steel axis B. The base of the cap *c*, which is four inches in diameter, terminates in an axis one inch thick, and two in length, the extremity of which is formed into a screw. The glass plate is put on this projecting part, and secured in its place by a nut of box wood, forced home by a key applied in the holes *i i*. Two rings of felt are applied on each side of the glass, to defend its surface from the contact of the wood and the metal; and the central hole in the glass, which is two inches in diameter, contains a ring of box wood, which prevents its immediate application to the axis.

"As it is necessary that the axis G should be parallel to the axis of the plate, in order that the conductors F F may move parallel to the plate itself, the pillar M is rendered adjustable by three bearing screws R R at the bottom, which react against the strong central screw T, and this is drawn downwards by its nut. The conductors F F are also adjustable by the sliding pieces *v v*, and the binding screws *w w*, which also afford an adjustment to bring the axis of each small conductor parallel to the face of the glass plate. A similar adjustment may be observed at the extremities of the arc I I.

"Fig. 31 represents a section of the moving part of the branch I I, one-half of its real size. A brass plate *a a* is screwed to the face of the capital K by three iron screws β. To this is screwed another ring δ δ, which affords a groove for the movable ring γ γ, into which the arms I I are fixed. This is accordingly applied in its place before the ring δ δ is fixed.

"The wooden part of the rubbers G G, fig. 29, is covered with thin plates of iron, excepting the surface nearest the glass. The intention of this is to maintain a more perfect communication between the rubbed part of the cushion and the earth, or the negative conductor, as the case may be.

"The plates of gum-lac Y Y, are applied to the rubbers, each by means of a thin plate of brass to which they are affixed by heat. There are two wires rivetted in these plates, which are thrust into correspondent holes in the wooden part of the cushion.

"The mahogany column A, ends in a square ζζ, upon which the piece K is fitted, and firmly applied by means of the screw and nut exhibited in the section." Nicholson's 4to *Journal*, vol. i. p. 87, or *Journal de Physique*, vol. xxxviii.

Consult also Cavallo's *Electricity*; Singer's *Electricity*; Espinasse, *Phil. Trans.* 1767; Nicholson, *Phil. Trans.* 1789; Keinmayer, *Jour. de Phys.* vol. xxxiii.; Higgins, *Phil. Trans.* 1778; Priestley's *History of Electricity*; Pearson's Machine, Nicholson's *Jour.* vol. i.; Wolf, in Gilbert's *Annalen.* 1802; Musnier's Machine, *Mém. Acad. Paris*, 1772; St. Julian's Machine, *Jour. de Phys.* 1788; Ingenhouz's Machine of Pasteboard discs, *Phil. Trans.* 1779; Rowland's *Description des Machines à Taffetas*, 8vo. Amst. 1785; Biot, *Physique*, vol. ii.

CHAPTER II.

Instruments for indicating the presence, and measuring the intensity of free electricity.

Electroscope and electrometer.

(45.) By the term *Electroscope* we understand an instrument which enables us to observe the presence of free electricity; while the term *Electrometer* ought to be reserved for some apparatus by which either its quantity or intensity might be measured. The two terms, it is true, have long been used almost synonymously; but as this manifest inaccuracy may lead to most incorrect descriptions, and would certainly vitiate our explanation of certain electrical phenomena, we propose, as far as we may be able, to confine the two terms to their strict etymological meaning.

As yet we are supposed to be unacquainted with the electric fluid in any other than its free state, obtained by the decomposition of the natural electricity inherent to all bodies. The fragment of paper or straw which we have spoken of, as attracted towards the excited amber or glass tube, points out to us the presence of that property or fluid which we term electricity; and therefore these minute substances afford the simplest possible illustration of the electroscope. If we observe with care the different distances at which these effects may be made manifest, we have, indeed, a rude approximation to a measure of the electrical excitement; in short to the electrometer; and hence it plainly appears that in some degree every electroscope is in fact an electrometer also, because we may, perhaps, obtain a rough estimate of the force exerted from the actual effect produced. Before we proceed to the description of a few of the best instruments of each kind, let it be premised, that we, at present, only seek to examine the state of free electricity distributed to a conducting body, to ascertain its nature, and to measure the intensity of its attractive or repulsive force. To the latent or accumulated electricities, the instruments before us have no present reference, and a disregard of these distinctions would hereafter induce serious errors upon our estimates of the effects of electrical apparatus.

(46.) The attraction of a small fragment of gold-leaf, or a thread hanging loosely from some point of suspension, was the first electroscope employed by the early experimentalists. Here the effect was produced by attraction, but after the repulsive property of two similarly electrified bodies had become known, it afforded a more convenient species of electroscope. Thus we arrive at the form of the instrument in the hands of the Abbé Nollet, who employed two threads freely suspended and hanging parallel to each other. On communicating electricity to those bodies, they became mutually repulsive, and the degree of their divergence might be measured by observing the shadows of the threads cast upon a graduated arc, traced out upon a board.

Bennet' electroscope.

(47.) *Bennet's electroscope.*—This instrument, in its most improved form, (independent of the condenser,) is represented by fig. 32; A B C D is a glass cylinder cemented into a brass stand E, and closed by a plate and rim A B. G is the brass cap of the electrometer, having a wire passing through a glass tube cemented into the plate A B, and to the lower end of this wire two small slips of gold-leaf *f f*, half an inch in width, and from two to three inches long, are affixed. From the opposite points C and D, two slips of tin-foil are pasted to the inner surface of the cylinder, and rise to a height some little above the ends of the gold-leaf *f f*, the lower ends of the foil communicating with the brass stand of the electroscope. The cap of the instrument is allowed to turn freely round, and by this motion the two gold-leaves *f f* are placed opposite to the two slips of tin-foil respectively. If now any electrified body be brought into contact with the metallic cap G, the two gold-leaves will share with the cap in the electricity received, and will mutually repel each other. Should this repulsion be so great as to drive the lower extremities of the leaves to the sides of the cylinder, they there come in contact with the tin-foil, and thus the electricity is conveyed away to the ground, and the leaves again collapse; but a feebler degree of electrical excitation only makes them recede from each other, as represented by the figure, and of course they continue in this position until the electrical charge is dissipated by the contact of the air with the cap, or by touching it with the finger or some conducting body.

This, on the whole, is one of the most convenient instruments for all ordinary electrical experiments, such as the examination of the nature of that electricity which is developed by any excited substance. Fig. 33 represents a section of the cap and neck of this instrument in its most improved form, in order more completely to avoid the contact of air, and thus to obtain more perfect insulation. A B is the top of the cylinder as before, G is the metal cap communicating with the gold-leaves, by means of a wire passing through a varnished cork or plug of silk *i*, cemented into a varnished glass tube of which K is

Singer's improvements.

tical ricity.

the lower extremity; this tube being also cemented into the centre of the plate A B. This improvement was introduced by Mr. Singer; its effect depends upon the brass wire, which conveys the electricity to the gold-leaves, being perfectly guarded from all contact with the atmosphere; for the body of air through which it passes being confined within the glass tube, can neither partake of the motions nor hygrometric variations of our common atmosphere. Mr. Nicholson proposed to employ two plates of thin brass instead of the two slips of tin-foil, so arranged, that by means of a tangent screw the upper parts of the plates might be brought very near to the two laminæ of gold. By this means more feeble degrees of electricity are made apparent; but the principle on which this improvement is founded, as well as that of the two slips of tin-foil, depends upon induced electricity, a subject which as yet has not fallen under our notice. For a more full account of this last improvement, see Nicholson's *Journal*, Sept. 1797.

ol- im- ement.

allo's.

(48.) *Cavallo's electroscope.*—Fig. 34 and 35 give a general representation of Mr. Cavallo's electroscope, which is principally employed in experiments on atmospherical electricity. A is a wooden stand, to which a case covering the whole instrument, when not in use, may be affixed by the screw seen in the figure. The glass cylinder and the slips of tin-foil are much the same as in the instrument recently described, except that the glass cylinder is contracted at the top, and terminates in a tube B. Into this tube B, a smaller tube of glass is cemented, the lower part of which is seen at C. Through this latter tube a wire passes to a metal or ivory plate C, perforated for the reception of a very fine silver wire, to the extremities of which two small pith balls are attached. D is a metal cap affixed to the central wire, and serving to protect the upper part of the tube B, whenever the electroscope is exposed to rain. The whole of the tube B, and the upper part of the glass cylinder are covered with a film of sealing-wax or varnish, for further protection from the penetration of moisture to the interior of the instrument.

allo's rtable ctro-ope.

(49.) Fig. 36, 37 and 38, represent a convenient pocket electroscope, employed by the same experimentalist; fig. 36 and 37, are views of a small glass tube $\frac{3}{8}$ths of an inch in diameter, and three inches and a half in length, with a loop of silk at one end *a*; *b* is a cork in the form of a spindle, so that it may be fitted into the glass tube by either end. To this cork is affixed a double silver wire, having at each of its extremities a delicate cone of cork or elder pith. In one figure the wires are seen deposited in the glass tube as a case, in the other figure they are suspended from its end by the reversing of the cork, and in an excited state. The glass tube serves as a handle, and is varnished throughout the lower half of its extent. Fig. 38 is a wooden case opening at one end by a screw, in which the glass tube is enclosed when not in use. At one end this case is mounted with a piece of smooth amber *d*, by the friction of which negative electricity is produced, and at the other end is an ivory knob *c*, insulated by a rim of amber *e*, for the production of vitreous electricity, which is easily effected by rubbing the ivory cap upon the sleeve of a coat, or any other woollen material.

bert's ctro-pe.

(50.) *The needle electroscope.*—This instrument, undoubtedly the most ancient, the most simple, and one of the most useful, has seldom been described. In fig. 39, A B is a fine metal wire, upon each end of which is a pith ball $\frac{2}{10}$ths of an inch in diameter. At the centre of this needle is an agate cap C, resting upon the point of a vertical wire D, inserted into a circular stand. E is a small slider for the purpose of balancing the two ends of the needle, so that it may remain in a horizontal position. It is essential also, that the concave surface of the agate cap, which rests upon the fine point of the stand, should be rather above the centre of gravity of the wire A B, otherwise the needle cannot remain suspended. The agate cap serves to insulate the needle, and, for further security, the stand may be placed upon a plate of shell-lac, or resin if necessary. There is, however, an additional preservative against the transmission of electricity from the needle to the stand. For if we suppose the cap to be made of metal, and not of agate, and we acknowledge that the pointed wire D will have a strong tendency towards the absorption of electricity; yet from the great length of the needle, compared with its diameter, the electrical charge will be determined towards its extremities; and the inner part of the cap, which touches the point of the stand, being a cavity within the general mass of the needle, will have scarcely an appreciable quantity of electricity distributed upon it.

Chap. II

It is obvious, that if an excited body, such as a stick of wax, or a glass tube, be brought near to either of the pith balls, an attraction will take place; and if the excited body be presented towards either side of a ball, and in the same horizontal plane, the motion of the needle upon its pivot will bring the ball into contact with the excited electric. The needle will become saturated with electricity throughout, and after separating the two bodies, and again bringing the one near to the other, a vigorous repulsion takes place. In this state the needle is prepared for the trial of the kind of electricity which is developed at the surface of any excited body.

Haüy's electroscopes.

(51.) *Haüy's electroscopes for mineralogical purposes.*—By a reference to fig. 39, we may also describe one of these instruments. A B is a metallic wire as before, but terminated by two small balls A and B, also of metal. The cap may be of agate or rock crystal, and the supporting stand similar to that already described. By a very simple process, founded upon well-known properties of the electric fluid, we may communicate to this needle either electricity, and yet make use of the same electric for the purpose in both cases. For example, by touching either of the balls with an excited stick of wax, the needle receives a charge of resinous electricity. On the other hand, let the needle be in its natural state, and let the excited stick of wax be brought near to one of the metal balls, but so as on no account to touch it. By this operation the natural electricity of the needle is decomposed, the vitreous electricity is attracted towards the ball nearest to the excited wax, and the resinous electricity of the needle is repelled to the opposite ball. Touch this ball with the finger, or any conducting body, for a second or two, and, *lastly*, remove the stick of wax. The needle now has a charge of free *vitreous* electricity; for that vitreous electricity, which was attracted towards the ball opposite to the wax, disperses itself over the whole needle; and the resinous electricity, which before neutralized it, has been removed by the conductor which touched the opposite ball. Haüy, *Traité de Mineralogie*, 2nd edit. vol. i. p. 191.

(52.) Other electroscopes, fig. 40 and 41, are employed by the same distinguished mineralogist to examine the feeble electricities of mineral bodies. In form, fig. 40 is nearly identical with the instrument last described; but, instead of one of the metal balls, there is affixed to the end of the needle a small bar of Iceland crystal. This variety of carbonate of lime has the property of becoming vitreously electric, by simple pressure between the thumb and finger, and hence the Abbé calls this instrument his vitreous electroscope. It need however never be employed in ordinary electrical investigations, and therefore we shall content ourselves with this brief notice of its construction and property for the present, as it will of necessity again appear in another part of this article.

Straw electrometer.

(53.) *Straw electrometer*. This instrument, represented in fig. 42, is frequently employed by continental electricians, though but little used in this country. Two very delicate laminæ are obtained by splitting a straw in a longitudinal direction, and then suspended by an exceedingly fine silver wire, passing through two holes in a plate connected with the cap of the electrometer. This part of the apparatus is enclosed within a square glass case or cage, having a divided arc of paper affixed to one of its faces, as seen in the figure. It is but in an imperfect degree that this instrument can serve as a measure of the actual intensity of repulsion of the free electricity communicated to it; but of course an estimate is obtained by observing the divergence of the straws in degrees of the graduated arc. It will be obvious, to any one acquainted with the nature of mechanical forces and the action of gravity, that equal degrees upon the paper arc at different distances from the vertical line passing through zero, do not indicate the presence of equal increments of force. This difficulty might however be removed by calculation; but there are also other sources of inaccuracy in this instrument when applied to the admeasurement of electricity, which neither calculation nor compensation can overcome. As an electroscope only, it is really a valuable instrument, being possessed of a high degree of sensibility, and not being so liable to injury as the electroscopes made of gold-leaf.

In fig. 43, is an enlarged representation of the mode of suspension, by a plate with two holes, the ingenious contrivance of Mr. Cavallo, by which means friction and rigidity, forces tending to impede the divergency of the wires, are in a great measure avoided.

Henley's quadrant electrometer.

(54.) *Henley's quadrant electrometer*. The instrument well-known by this title forms a very common appendage to the electrical machine. Fig. 44 represents a wooden stem six or seven inches long, surmounted by a ball. Into the side of this stem is affixed a semicircle of wood or ivory, the arc of which is graduated and figured; the numbers beginning from the lowest point, and terminating at the end of the first quadrant or 90 degrees. At the centre of the circle a pin is inserted, bearing a light index of cane, having a pith ball C at its extremity. Having fitted the lower part of the stem into a hole in the prime conductor of a machine, the index rod and pith ball will hang down in a vertical position, parallel to the upright stem, and cover the zero of the graduated arc. But immediately upon the communication of electricity to the conductor, the pith ball is repelled by the stem, and continues by its divergency to mark upon the limb of the semicircle the intensity of the repulsive force produced. Either a calculation, or a previous unequal graduation of the semicircle, would be necessary for the reasons already stated, to obtain accurate relative measures from this instrument also; but as this electrometer is not easily injured, and serves roughly to estimate the state of activity of an electrical machine, it has become a frequent accompaniment to the prime conductor.

Robin

(55.) *Robinson's comparable electrometer*. It would be an act of injustice were we to omit to mention a very elaborate instrument of this species, contrived by that excellent electrician the late Professor Robinson, with which he was enabled to obtain a much more accurate measure of electrical attractive and repulsive forces than any of his predecessors. The instrument is now we believe entirely in disuse, from the greater simplicity and delicacy of M. Coulomb's apparatus; and therefore for a detailed description of Robinson's electrometer, we beg leave to refer our readers to a republication of the physico-mathematical writings of the Professor, by his able editor Dr. Brewster.

Coulc torsio electr meter

(56.) *Coulomb's electrical balance*. For the present, we propose to content ourselves by cursorily describing a very sensible electrometer, on M. Coulomb's principle of torsion, of greater delicacy than any hitherto mentioned, as a mere indicator of the presence of electricity; and one which, with proper precautions, affords an absolutely accurate estimate of the attractive or repulsive force of the free electricity communicated to a mass of matter of given superficies.

A B, fig. 45, is a cylindrical glass jar, covered at the top by a circular glass plate, with a hole in its centre. Through this hole, a single fibre of the silkworm's web, or a very delicate silver wire, descends nearly to the bottom of the jar, and carries at its lower extremity a transverse bar. This bar consists of either a filament of gum-lac, or a silk thread or piece of straw coated with sealing-wax; at one extremity is a small pith ball, at the other a disc of varnished paper, as a counterpoise to the ball. The upper end of the wire is affixed to a sort of button C, with a small index, capable of being turned round upon a circular plate F, divided into 360 degrees. One side of the jar is perforated, to allow of the insertion of a small bar E, having a metal sphere at each of its ends, the one being at the exterior and the other at the interior of the jar. By turning the button C, or the index, the needle may be brought into any required position with regard to the bar E. Now it is found by experiment, that the angle of torsion of the delicate wire of suspension we have described, varies in a direct ratio with the force acting upon it (within certain limits,) and therefore if the bodies D and E be placed in contact, and then similarly electrified, the distance to which they are repelled by the angular motion of the ball D, is a measure of the repulsive force exerted, be the law of that force what it may. Hence, by employing different forces of torsion which are known, and which may be measured upon the graduated head, to produce an equilibrium between different repulsive or attractive forces, which may be measured upon a graduated arc of paper pasted round the jar, the actual laws of these forces may be calculated.

Strictly speaking, the chord of the arc described is the distance to which the mutual action of the balls extends, and is therefore the true measure of the force; but at present we only attempt to describe the instrument in general terms, and to speak of an approximate result. In a similar manner the distance through which the ball is made to move, i. e. the torsion it is enabled to produce by attraction, when the fixed and movable balls have opposite electricities, may become an accurate measure of the attractive force. A much more minute description of this valuable instrument, in its most improved form, and an accurate investigation of the laws of its action, will form an essential introduction to our theoretical electricity.

(57.) The electroscopes now described, with the addition of the simple stand and pith balls before mentioned, are all that apply to electricity, so far as the plan of this article has as yet made us acquainted with it; that is to say, in its free state. Other and more complicated instruments will be required when we shall be called upon to examine latent or accumulated electricity; but there is yet one important problem to be solved, which has, strictly speaking, its place in the present chapter.

It will presently appear that upon an electrified and insulated sphere of conducting matter, the electricity is distributed as a stratum of fluid of uniform thickness throughout; but this is true of masses of matter of no other form. It becomes then desirable to be in possession of some electrometric apparatus, by which we may ascertain the quantity of fluid resident at any given point upon the surface of an excited body. For the solution of this problem we are again indebted to the sagacity of M. Coulomb. He found that by affixing a small circular disc of gilt paper to the end of an insulating filament of gum-lac, he could obtain by a single contact with any excited and insulated conductor, a charge of electricity upon the disc, proportionate to the quantity of electricity resident upon the conductor at the point where the contact had been made. For the success of this method, it is required that the disc, which M. Coulomb calls the proof plane, should be small in comparison of the conductor to be touched; so that the addition of the new conducting body, during the moment of contact, may scarcely interfere with the laws governing the distribution of the fluid; and also that the proof plane may, as nearly as possible, only form as it were a second particle, to share electricity with some one given particle belonging to the great mass of the electrified conductor. Having thus acquired the means of removing a quantity of electricity from any point, proportionate to the actual quantity of fluid at that point; or, which is the same thing, proportionate to the electrical intensity at that point; it is easy to measure, by the torsion balance, the repulsion exerted by the proof plane upon the movable ball charged with a known electricity, and thence to infer the quantitative distribution of electricity for that one point. In a similar manner, a series of comparative estimates may be obtained for all other required points upon the excited body, until the general form of the distributed bed of fluid be ascertained.

For other electrometers of this sort see D'Arcy, *Mém Acad. Par.* 1749; Richman, *Nov. Com. Petrop.* vol. iv p. 301; De Luc, *Meteorologie*, vol. i. p. 376; Camus, *Jour. de Phys.* vol. vii. p. 520; Terry, *Jour. de Phys.* xxiv. p. 315; Canton's improved by Cavallo, *Phil. Trans.* lxvii. p. 388.

CHAPTER III.

On the spontaneous motions of the electric fluid.

INTRODUCTION.

(58.) UNDER this title we propose to arrange and consider a certain class of phenomena, which (upon the hypothetical assumption that each kind of electricity is a fluid,) may be accounted for by its self-expansive property; that is to say, by the repulsion which all its molecules exert upon each other. It may not at first appear that this class of facts includes the circumstance of an electrified and insulated conductor, apparently losing *all* its electricity by the contact of another conducting body; but the application of our reasonings will be clearly seen by a careful examination of the conditions of the case in which the supposed difficulty is involved. Let the second conductor which is brought into contact with the electrified body be of finite magnitude and insulated; in this case the electrified body will not lose *all* its electricity, but a division of the electricity will take place between the two conductors according to certain laws. Again, let us take the extreme case, from which the objection has been framed. Let the electrified conductor communicate for an instant with the earth, and the same mode and law of action will produce apparently an entire abstraction of the free electricity, because in this case the partition of fluid takes place between the whole earth and the electrified body; and as the magnitude of the latter bears no appreciable ratio to the magnitude of the former, there will be no appreciable quantity of free electricity left upon the originally excited body.

Conducting power.

It may easily be shown that electricity does possess some property, the effects of which we can explain, and even calculate, upon the supposition of this mutual repulsion existing between the molecules of the same fluid; for if a portion of it, in its free state, be communicated to any one from among the several substances which seem in a greater or less degree to suffer its progress through them, either a complete transmission is effected, or else a distribution of the fluid takes place with regard to both the bodies according to invariable laws. Some substances, as we have already seen, readily afford a passage to electricity, whilst others, with greater or less obstinacy, refuse to do so. This is termed the *conducting power*, a phrase which does not precisely express the true conditions of the case; for it has been proved that the particles of matter of different kinds, whether from conducting or non-conducting bodies, have no peculiar affinities for the electric fluids, and therefore it is more probable that some term implying a passive property in the substances spoken of, would give a more accurate description of the process. *Conducting power* is however an established phrase, and therefore will henceforth be employed here in its ordinary acceptation; and the investigation of this property in different substances, will form the subject of the first section of this chapter. In the second, we shall treat of the *dissipation* of electricity, being the cause of the spontaneous return of an excited body to the natural state of electrical equilibrium; and in the third section, we shall give a summary (as far as fact is concerned) of the mode of *distribution or arrangement* assumed by the fluid in any electrified substance.

§ I. *On the conducting power of different substances.*

(59.) Communicate to a gold-leaf electroscope either electricity, so as to produce a divergence between the suspended leaves. If now we touch the cap of the electroscope with a glass rod, no effect will be produced; that is to say, the charge of free electricity is not by that process conducted away or suffered to escape; but if we touch the cap of the electroscope with the finger or a rod of metal held in the hand, the contrary effect is produced, the electricity escapes, and the leaves collapse. Here then we have a familiar example of a *non-conducting* and a *conducting* body. With more or less of strict accuracy, under one or other of these two denominations, all substances may be arranged, and such has been the plan hitherto adopted. Thus we have conductors and non-conductors; the latter are also sometimes called insulators.

As is the case however with many systematic classifications, few bodies will be found to belong strictly to either division alone, and several substances might appear with almost equal propriety in both series. There is in fact a progressive order, in which all bodies may be arranged, beginning with that substance which possesses either property in the greatest perfection, and proceeding through the gradations of many other substances to the opposite extremity of the scale; but the precise point where conducting power ceases, and the contrary property begins, is in some cases uncertain, and in very many it depends upon a circumstance totally adventitious, viz. the hygrometric state of the body submitted to experiment. For these reasons we are inclined to depart from the ordinary plan, and to arrange these substances all in one column, beginning with the best known conductors, and terminating with those that are the worst; or, in other words, that are the most perfect non-conductors. There is doubtless some difference in their respective powers, even among the metals, which are the best conductors; but from the high degree of intensity of ordinary electricity, they all seem to transmit the fluid with equal facility. There is however reason to conclude, that delicate experiments would assign to the metals different degrees of permeability; for such is found to be the case with the less intense electricity developed by galvanic agency; and the order assigned to them in the subsequent list, is the result of Sir H. Davy's experiments with the last-mentioned agent.

The following observations of Mr. Singer are applicable to the subject of our present investigation. "The tendency of the charge to pass through the best conductors, offers a measure of conducting power; for if various substances of the same length and size are introduced at once into the circuit, that through which the electric fluid passes is the best conductor. Or, if they are introduced successively, that which conveys the charge most completely may be considered as the best conductor. Metals, although the most perfect conductors we know, oppose some resistance to the motion of electricity; and a charge will even prefer a short passage through air, to a circuit of twenty or thirty feet through thin wire." The inference deducible from these experiments of Mr. Singer has been much strengthened by recent experiments of Professor Cumming, which are given in the first volume of the *Cambridge Transactions*, wherein it is proved that the analogous fluids, the magnetic, the galvanic, and the thermo-electric are materially influenced as to the rate or perfection of their transmission, by the magnitude of the conductors through which their passage is effected.

Again, with regard to the other class of bodies, it has been proved by Coulomb, that no substance can strictly be called a non-conductor; because electricity of great intensity will traverse small lengths of all bodies; but that there are certain limits within which a few substances may in practice be employed as such. Hence the insulating power of rods of substances of this class varies, directly according to some power of their length, and in some inverse ratio of the intensity of the electricity which they are required to insulate.

The black line, forming a division in the following table, is the position, according to Mr. Singer, at which we may suppose the conducting power to cease, and the insulating power to commence. In regard to several substances, placed about the middle of the table, such as the animal and vegetable bodies which contain moisture, and the earths in their ordinary state, we must consider them made up partly of conducting and partly of non-conducting matter; thus the pure earths and alkalis are non-conductors, but from the moisture which usually accompanies them, they become imperfect conductors.

Tabl
bodi

Table of the Conducting Power of bodies, beginning with the most perfect, and ending with those which are the least so, or that most nearly approximate to the property of Non-conductors.

All the metals.
Silver.
Copper.
Lead.
Gold.
Brass.
Zinc.
Tin.
Platinum.
Palladium.
Iron.
Well-burnt Charcoal.
Plumbago.
Concentrated Acids.
Powdered Charcoal.
Dilute Acids.
Saline Solutions.
Metallic Ores.
Animal Fluids.
Sea Water.
Spring Water.

Rain Water.
Ice above — 13° Fahrenheit, (*a*)
Snow.
Living Vegetables.
Living Animals.
Flame.
Smoke.
Steam.
Salts soluble in Water.
Rarefied Air, (*b*)
Vapour of Alcohol.
Vapour of Ether.
Moist Earths and Stones.
Powdered Glass, (*c*)
Flowers of Sulphur, (*c*)

Dry metallic Oxides.
Oils, the heaviest the best.
Ashes of vegetable Bodies.
Ashes of animal Bodies.
Many transparent Crystals, dry.
Ice below — 13° Fahrenheit.
Phosphorus.
Lime.
Dry Chalk.
Native Carbonate of Barytes.
Lycopodium.
Gum Elastic.
Camphor.
Some Silicious and Argillaceous Stones.
Dry Marble.
Porcelain.
Dry vegetable Bodies.
Baked Wood.
Dry Gases and Air.
Leather.
Parchment.
Dry Paper.
Feathers.
Hair.
Wool.
Dyed Silk.
Bleached Silk.
Raw Silk.
Transparent Gems.
Diamond.
Mica.
All Vitrifactions.
Glass.
Jet.
Wax.
Sulphur.
Resins.
Amber.
Shell-lac.

(*a*) According to M. Achard of Berlin, who proved, in 1776, that a rod of ice two feet long, and two inches thick, at 18½° Fahrenheit, was a very imperfect conductor; and that at — 13° Fahrenheit it would not conduct at all. He then, having very ingeniously frozen some water, so that it should contain no air bubbles, formed it into a spheroid, and having mounted it upon an axis, was able to employ it as an ordinary electric globe capable of a high degree of excitability. MM. Jallabert and Priestley had before proved that ice of the ordinary temperature, in our warmer climates, is a conductor.

(*b*) Possibly acting in a manner quite different from all other bodies near to it in the table, for in whatever manner they either transmit or allow the progress of electricity, the action of rarefied air is simply due to the removal of a substance which presents a most powerful resistance to the motions of the fluid. It would appear that in all our attempts to form a more perfect vacuum than that which the air pump will give, we only substitute in place of the air a sort of metallic atmosphere, which, of course, is highly favourable to the transmission of electricity. Such at least is the view we are inclined to take of the matter, although we admit that the subject is one in which considerable difficulties are involved. Walsh, Brooke, and Morgan made numerous experiments to ascertain whether a vacuum was or was not a non-conductor. Morgan inferred (*Phil. Trans.* 1785,) that it was a perfect non-conductor, because he could produce neither electrical light nor a charge in it. The former is quite consistent with the origin which we have assigned to electrical light, and therefore proves nothing; and we confess that we consider the latter argument as easily set aside by the explanations we shall hereafter give of the motions of electricity. At present, therefore, it appears probable that a perfect vacuum is a perfect conductor.

(*c*) From Van Swinden's experiments.

(60.) The greatest distance to which electricity might be conveyed, was a question which exercised the ingenuity of some of the early experimentalists, although the velocity with which it traversed the metals was their primary object; of these researches we have already given some account. An electrical charge from a battery is stated to have been compelled to traverse a circuit of four miles; and although Singer, whose opinion is entitled to respect, has doubted the accuracy of these experiments, yet, on examining the papers in which they are described, it does not appear that the result is either improbable, or that any source of fallacy can have escaped the observation of the experimentalists. There does not, in fact, appear any thing in the nature of the case, to lead us to a contrary conclusion; for although we admit that an electric discharge will prefer a very short passage through air, to a very long one through a thin wire, yet we still arrive at this point, that electricty of high intensity will force itself a passage through a thin stratum of air, but that at much lower degrees of intensity it is capable of passing through metal; and as the conditions of the case may be so arranged that it shall traverse the air in preference to the metal, there must be some point at which the facilities afforded by these channels are equal. The density, hygrometic state, and thickness of the plate of air might form one side of an equation; and the nature of the metal, together with the thickness and length of a wire formed from it, might constitute the other side. But in this reasoning, we must suppose the intensity of the electricity given, and it would probably prove a more complicated question, were we to attempt to introduce into our formula an element corresponding to variations of electrical intensity.

Of the immeasurable velocity with which the motions of the electric fluid must be conceived to take place, we are able, perhaps, to form some idea, by considering the great mechanical momentum which it is capable of producing, although as a fluid it seems to us absolutely imponderable.

(61.) The smallest length to which some imperfectly conducting bodies may be reduced without losing their insulating power, has been examined by M. Coulomb, and he found that in each case this length depended upon the intensity of the electricity which the fibres were required to insulate, and the state of the atmosphere at the time of the experiment. It appeared that when electricity was communicated to a ball, suspended by a fibre of any insulating substance, the loss of electricity was at first much greater than could be accounted for from the dispersion in air alone, and therefore this loss was due to the imperfection of the insulation; but that after a time, when the electricity had diminished to a certain degree of intensity, no further diminution took place, except that which was due to the action of the air. Hence, at some degree of intensity in the communicated electricity, (in a given state of the air) a filament of given length becomes a perfect insulator. Or, which is the same thing, these imperfect insulators follow some law according to which some length may be found (on a given day) just capable of insulating electricity of any given intensity. The general law for all fine cylindrical fibres, such as hair, silk, filaments of gum-lac, &c. is, that the intensity of the electricity which different portions of the same substance will insulate, varies as the square root of the length of the fibre. In which case the nature of the substance, the diameter of the fibre, and the dispersive state of the air, are supposed constant.

Few comparisons have been instituted between different substances, but Coulomb found that the density of the electricity, which a fibre of gum-lac would insulate, was ten times as great as that which could be insulated by a silk fibre of equal length and equal diameter.

(62.) The next point for our examination, is one of extreme interest and curiosity. Do all bodies conduct both the electricities with equal facility? This question has only recently been submitted to any thing like a strict experimental investigation, and it is to M. Erman, of Berlin, that we are principally indebted for our information upon this subject. In these researches, however, he was compelled to employ the weak intensity of galvanic electricity, which we have before hinted might be resorted to with advantage, in examining some other questions connected with the conducting power of substances. M. Erman has proved, that besides the classes of conductors and non-conductors, that are such universally, there are some substances which completely cut off the passage of one electricity, while they as freely suffer the progress of the other. The more minute details of these researches must be reserved for the Galvanic part of this article. (*Jour. de Phys.* vol. lxiv.) The experiments of Mr. Brande, described in the *Phil. Trans.* for 1814, appear more properly to depend, as he has suggested, upon the electrical states of bodies induced by chemical action; and for this reason will be reserved to that part of our article in which the connection between Chemistry and Electricity will be discussed.

(63.) At present we can scarcely be said to have any knowledge of the influence which the other imponderable physical agents are capable of exerting, either for the increase or diminution of the conducting power of substances. As far as experiments have hitherto shown, increased heat neither tends to accelerate nor to retard the progress of electricity through metallic wires; and upon the electric fluid itself, it has not the least perceptible influence; for if powerful sparks be drawn from a mass of ice, they are not found to differ in temperature from similar sparks taken from a mass of red-hot iron; and if the wires by which an electrical or galvanic circuit is completed be made to pass through furnaces, so as to be intensely heated, no appreciable effect upon the electricity is produced. Still there are analogies which would lead us to suppose that there may be such an action, although to us it is at present utterly inappreciable, for among conductors less perfect than the metals, we meet with marked instances of such effects. Upon some of these bodies the addition or abstraction of sensible heat, produces an increase or a diminution of conducting power. Thus charcoal is a better conductor when hot than it is when cold. Glass, when cold and dry, is a non-conductor, but when heated to redness it becomes a conductor. Resins, which in their ordinary state are the best of non-conductors, entirely lose this property, and adopt the contrary one when they are rendered fluid by heat. Ice below —13° Fahrenheit is a non-conductor, but above this temperature it is a conductor. By a further increase of temperature it becomes water, and is still a conductor, and when heated is a still better one than it is at its ordinary temperature; this property continues to it even in the state of vapour. Air, however, has never been made a conductor of electricity, in the true sense of the word, by any degree of heat that has been communicated to it.

The conducting power of charcoal has been found to vary considerably, according to the different degrees of heat to which it has been subjected in its manufacture; it also varies with the different substances from which it may have been formed, so that we may suspect certain slight changes either in its chemical or mechanical structure, to be capable of producing these effects.

In general the chemical nature of substances seems to have but little immediate connection with their conducting powers, beyond the supposed uniformity of action existing between all the metals on one hand, and all the resins on the other; and the only attempt to speculate upon what may be the real nature of the conducting or non-conducting property, has been made by M. Coulomb. The opinion of this admirable philosopher is of course entitled to great respect, but is in this case unsupported by any fact, and is only advanced as a possible supposition. He considers the conducting power to depend upon the relative distances between the conducting particles entering into the constitution of a mass of matter; and that as these particles are at different distances in different bodies, the electric fluid, in its passage from one molecule to another, has a non-conducting space to traverse of variable magnitude. These conducting molecules being uniformly disposed in any given body, it follows that the non-conducting spaces, and therefore the imperfect conducting power, is constant for the same body.

Whatever may be the cause or mode of its action, we must in some sense consider the non-conducting property a force, for it gives to the particles of matter that are possessed of it, the power not only of preventing the motion of the electric molecules along the surface of a non-conductor, but it enables the body itself to retain them with some degree of power. Such, at least, is the inference we are inclined to draw from the circumstance that of two excited substances, the one a conductor, and the other a non-conductor, placed in vacuo; the non-conductor retains its electricity much longer than the conductor does.

§ II. *On the gradual dissipation of electricity.*

(64.) It must already have been remarked, that in all cases where an excited body has been left exposed to the action of the air, even in a state of insulation, a partial or total loss of its electricity takes place. Thus the pith balls, described in art. 16, if at first divergent from excitation, will, in process of time, without the contact of any conducting body, again collapse. There appear to be three principal causes cooperating to produce this effect.

1. The imperfection of the insulating property in all known solids.
2. The contact of successive portions of air, of which every particle carries away its own charge of electricity.
3. The deposition of moisture upon the surface of an insulating body, tending to increase its conducting power.

(65.) With regard to the first of these causes, it would appear that there is no such thing in nature as a perfectly insulating body, that is to say, there is no substance known of which any portion, however small, will insulate any electricity however great its intensity. The proof of this is abundantly simple; for if a small cylinder of any substance be taken from among those which are considered the best insulators, and placed so as to have one end in contact with the prime conductor of an electrical macine, it will be found, upon trial, that after a short interval of time has elapsed, even those points most distant from the excited conductor have acquired electricity of the same kind, with which the conductor was charged. We have, however, mentioned already, that in practice, by diminishing the intensity of the electricity, or increasing the length of the substance it has to traverse, a sufficiently accurate degree of insulation may be obtained.

2. In the next place, every particle of air in contact with an excited body, must itself receive a charge of electricity, and the effect of this charge will be to produce a repulsion between the particles and the body, and a consequent separation, by which some other particle will be in the same manner admitted to receive a similar charge, and thus a perpetual diminution of the electrical intensity of the excited body is produced. It is further clear, that whether the aqueous vapour, which the air contains, be in combination with the aërial molecules or independent of them, the resulting effect of its presence is to aid the dissipation of electricity; for in the one case it will increase the conducting, and therefore the receiving power of the aërial molecules, while in the other it would add a highly attenuated atmosphere of an almost perfectly conducting substance.

3. The third source of electrical dissipation arises from the same cause, operating in a different manner; here the vapour, being condensed, is deposited upon the surface of the insulating body, and thus a chain of conducting particles is formed to convey the electricity to the earth.

(66.) The experiments by which the actual effects of these disturbances, under given circumstances, have been investigated, are among the most laborious researches of M. Coulomb. The instrument which he employed on this occasion has already been incidentally mentioned; but as almost every application of it to a practical purpose involves some calculation, and presupposes a knowledge of the exact laws of electrical action, we shall here present such a summary of his results as may be thought essential to the practical applications of our subject, and leave their strict investigation to the more powerful resources of theoretical electricity.

In attempting to avoid the first of these sources of electrical dissipation, M. Coulomb was very successful; for he found that within certain limits, and by adopting certain precautions, its effects became absolutely imperceptible. Thus when the charge of electricity communicated to the body was such as not to produce a high degree of repulsive intensity, a small cylinder of sealing-wax, or gum-lac, half a line in diameter, and eighteen or twenty lines in length, would be sufficient to insulate a pith ball of five or six lines in diameter. That complete insulation, as far as the support was concerned, had thus been obtained, was proved by this fact, that the gradual diminution of electrical intensity measured by repulsion was the same, whether one or more of these cylinders were employed for the support of the electrified ball.

By means of a very delicate torsion electrometer, Coulomb then examined the conjoined effects of the two remaining causes of electrical dissipation; he found that by carefully selecting such substances as were most unfavourable to the reception of moisture, and by employing cylinders, or rather filaments of small diameter, so that but little could be received upon their surfaces, he was enabled to reduce the dispersive action almost entirely to the second source of loss mentioned. The following are his general conclusions:

1. That in a given state of the atmosphere (according to barometric, thermometric, and hygrometric indications,) the dissipation in any given short time, varied directly as the repulsive intensity of the charge.
2. Hence, by ascertaining upon any day the rate of dissipation for any given intensity, the dissipation for any other intensity may be calculated from the above law.
3. Hence also, having given the initial intensity, and the law of dissipation ascertained by experiment, the repulsion, after any time elapsed, may be determined.

(67.) To this point Coulomb had arrived, employing balls of the same substance, and of the same magnitude for his experiments. He then proceeds to prove that the law is general for balls of different substances, pith, copper, and wax, whatever be their magnitudes. An inquiry here obviously suggested itself, connected with the very different natures of these bodies. Does an insulated and electrified globe of wax, or any non-conductor, retain its electricity by a peculiar and predisposing affinity different from that by which a copper ball, or one from among the conducting class, retains its electricity? Experiments seem to prove the contrary, and the inference which may be drawn from them is, that the air alone, by its pressure and non-conducting property, performs a very principal part at least in restraining the electric fluid from expanding itself in space and leaving the excited body.

From spherical bodies we are next led to consider the loss of electricity from substances of any regular or irregular figure; and it appears that all such cases are subject to laws identical with those already described. In making these experiments, however, there are some circumstances to be taken into the account, to which we have already adverted in speaking of the effect of points in dissipating electricity; for this reason it is necessary that in these experiments, electrical charges of very low intensity should be communicated to bodies with angular points or projecting surfaces.

A curious experiment connected with this part of our subject has been made by M. Biot. He wished to ascertain whether the dissipation was the same, with whichsoever of the electricities the ball of the electrometer was charged; and he found that there was so little difference in the effect produced, as to lead him to infer, that with perfect accuracy of experiments, the loss would have been equal in each case.

(68.) In the next place, considering the law of dispersion ascertained for perfect insulators, it was easy to separate and determine the loss arising from imperfect insulation. It appeared that a ball, highly charged with electricity, and suspended by a silken thread, suffered a much more rapid dissipation than could be due to the effect of the air alone; but that the electricity arrived at length at a certain point of diminished intensity, such that the silk now insulated as perfectly as the gum-lac had before done, and the gradual loss became precisely such as might be accounted for, from the action of the air alone. It was proved, moreover, that the greater was the loss from the state of the atmosphere, the greater also was the increase of the loss from the imperfection of the insulation.

(69.) Of the ordinary atmospherical changes; those which have the most intimate connection with the presence of moisture, seem, as might have been expected, to produce the most material effects upon the dissipation of electricity; but Coulomb's most careful investigations did not lead him to place confidence in even the united indications afforded by the barometer, thermometer, and hygrometer, for producing a law of electrical dissipation, which could be accurately expressed in terms of these elements. It appeared, in fact, that some time must always elapse, before these instruments exhibited the true state of the air with reference to the power of electrical dissipation. Hence, on different days, when these three instruments seemed to indicate the same state of the atmosphere, the quantities of electricity lost in a given time would not be the same. It appeared that on a sudden change of weather, by which the hygrometer indicated increased dryness in the atmosphere, the quantity of electricity lost in a given time was not diminished so much as, from calculation, it ought to have been. M. Coulomb attempts to account for this on the supposition that there is an adhesion between the air and the vapour, which interferes with the operation of the hygrometer; so that the material by which in this instrument the indications are obtained, can only be affected by that portion of moisture which is entirely free from the aërial particles, and that as these are only gradually separated, the dissipation of electricity being the more subtle agent, is assisted by certain particles of aqueous vapour remaining in combination with the air, but of which the hygrometer is not sensible.

§ III. *Distribution, or local arrangement, of electricity.*

(70.) Does electricity reside only at the surface of bodies, or is it expanded throughout the whole of their substance? This important question did not escape the penetration of some of the early experimentalists upon the subject before us. Watson showed that the electric fluid did not pass along the exterior surface of a metallic rod; for he found that an entire coating of wax did not in the least impede the transmission of any charge, large or small, through the conductor. Experiments to the same purpose were made about the same time (1746,) by M. le Monnier. By considering the equal division of electricity, which takes place between two bodies of equal surface and similar form, whatsoever be their nature, as proved by an experiment of Coulomb, and that the same takes place if one body be a solid, and the other the thinnest possible shell of matter, we may justly be led to suppose, that all the electricity which any excited body is capable of retaining, resides somewhere in the region of the exterior surface of the body. Thus far, however, M. Achard had arrived in 1780. (*Mém. Acad. Berl.*)

(71.) The following experiment contains an elegant practical demonstration of this truth. Let S, in fig. 46, represent any spheroid of conducting matter, suspended by a thread of some perfectly insulating substance. Let E E be two caps formed of gilt-paper, tin-foil, or any conductor, and such that when united they accurately fit the surface of the spheroid. An insulating handle of gum-lac is also affixed to each of the caps. Now let there be communicated to the ball S any degree of electricity, and then carefully apply to its surface the two caps, holding them by their cylinders of gum-lac. Upon the removal of the caps, it will be found that every particle of electricity has been abstracted from the spheroid, so that it will no longer affect the most delicate electrometer; whilst the two caps will be found, upon accurate trial, to have acquired precisely the same quantity of electricity which formerly resided upon the body S.

(72.) A proof of the same position, by M. Coulomb, is, however, more general, inasmuch as it is applicable to bodies of every possible form. The general outline of the experiment is as follows: By means of the torsion electrometer, and the proof plane which we have already cursorily described, Coulomb was able to measure the quantity or intensity of the electricity conveyed away by the proof plane from any point in an electrified body; and the quantity thus removed was proportioned to the quantity of fluid distributed to the point at which the contact had taken place. Having prepared the substance upon which he proposed to examine the distribution of the fluid, by perforating it with several holes, reaching to different depths, and being able by means of the proof plane to convey away charges of fluid from the bottom or sides of these holes, if any there existed, he found that the whole charge of electricity was arranged round the outer surface of the body, and that not a particle of electricity was to be discovered at the bottom or sides of any of these holes.

(73.) We borrow from M. Biot the following very elegant experiment, exhibiting the effect of increasing the surface over which a given quantity of electricity is distributed. A B, fig. 47, is an insulated cylinder, movable round an horizontal axis, and capable of being turned by an insulating handle M. Around the cylinder is coiled a thin lamina of any metal R, the end of which is semicircular, and has attached to it a silk thread F. The metal and cylinder communicate with an electroscope formed of two linen threads *f f*, to the extremities of which two pith balls are attached. On communicating to the metallic riband a charge of electricity, the balls and the threads diverge. Upon taking hold of the silk thread, and unrolling the metallic riband from the cylinder, the pith balls gradually collapse, and thus indicate a diminution in the intensity of electrical repulsion; and if the riband be sufficiently long, the electrical charge may be spread over so great an extent of surface, as to allow the balls entirely to collapse; but on winding up the riband again, the intensity is restored and the balls diverge to the same extent as before, allowing only for the small dissipation of electricity which may have been produced by the contact of the air during the experiment.

(74.) On the whole, then, it appears that electricity does not reside upon the exterior surface of an excited conductor, but that it is in reality within the substance of the body, but extending to a depth so slight, as to be inappreciable by any known methods of experiment.

(75.) The next point to be ascertained, relates to the intensity of electricity disposed around the surfaces of bodies of different forms; or supposing (if not in reality, at least for the sake of illustration,) that the fluid is disposed as a stratum of some material substance, to find the relative thickness of that bed at different points. In the case of an electrified and insulated sphere, the intensity is found to be the same at every part of the surface. But in a cylinder, or bar, the electrical intensity is much greater at the ends than at the middle, and the ratio of this inequality of distribution increases very rapidly in proportion to the dimension of the diameter of a bar of given length.

(76.) A few other cases of electrical distribution may here be mentioned as facts, the rationale and demonstration of which it must be left for our theory to explain. Two spheres of conducting matter being placed in contact, and charged with either electricity, the fluid will be distributed between them, and repose at their surfaces in the following manner: At their point of contact there will be no free electricity, but the bed of fluid will increase in thickness from this point over each of their surfaces according to a law, depending upon the ratios of their respective diameters, and will arrive at its maximum thickness on each sphere at the point diametrically opposite to that of contact. The maximum thickness of the bed upon the smaller sphere, will be greater than the maximum thickness of the bed upon the larger sphere. After the *distant* separation of the spheres, each will retain the electricity it possessed during the contact, and the quantity retained by each, and therefore the electrical charge which each will now have uniformly distributed over its surface, will be determinable also by the ratio existing between the radii of the spheres. The smaller will evidently retain a charge of greater intensity; because the actual quantity upon its whole superficies, though less than the quantity upon the superficies of the larger globe, is disposed over a much smaller surface.

The facts which have now been recited concerning the distribution of electricity upon two spheres which have been in contact, are true only when they are removed to such a distance from each other, as to preclude all mutual influence, a subject which we shall not be able to investigate, until a further acquaintance with the principles of electrical induction.

Upon a comparison of the quantitative distribution of electricity between an excited globe and a circular disc placed in contact, M. Coulomb found that this distribution was in the direct ratio of the entire surfaces of the two bodies.

(77.) It follows from these observations, that we may represent the arrangement of electricity upon an insulated metal sphere by the diagram fig. 48. In this case the figure is in one respect designedly incorrect, because the dotted line which is supposed to represent the exterior surface of the stratum of fluid is without the sphere, when, in fact, to produce a true representation of the case, it ought to coincide with the surface; but we shall find this a necessary evil in order to make the electrical distribution and tension which is produced in bodies of other forms, the more intelligible. We suppose then a line *p*, perpendicular to the surface of the sphere at any point, to measure the thickness of the bed of fluid, and therefore to be, according to some ratio, a representation of the electrical intensity at that point. In a similar manner, fig. 49, may be taken as a representation of the quantitative distribution of electricity at different parts of the insulated and electrified bar A B. The series of ordinates drawn from the bar to the points *m n o p q*, may be supposed to represent the thickness of the electrical stratum at these points respectively; and from a series of such ordinates, we may obtain the dotted line *m n o p q*, to give a general representation of the distribution of the electricity upon the bar. Now it has been proved that the pressure exerted by electricity, which we may term the electrical reaction, against the air, varies as the square of the thickness of the electrical stratum; and therefore the squares of all these ordinates may represent the electric tension at these points respectively. By an application of this reasoning to the action of a point, we shall readily account for the powerful dispersion of electricity which we have before mentioned as taking place from all bodies of that form. In fig. 50, let C be the extremity of the electrified prime conductor of a machine; D a metallic point communicating with the conductor. On the principles we have laid down, the dotted line *n o p*, will give some idea of the distribution of the fluid; and the perpendicular line P *p* may be supposed to represent the thickness of the stratum of fluid accumulated at the extreme point P. Supposing this point P perfectly acute, the form of the curve $n\ o\ p$, will depend principally upon the general form of the conductor, and the quantity of electricity communicated to it. Now the resistance of the air which is the force opposing the dispersion of electricity from conducting surfaces of all kinds, varies with its density, its hygrometric state, and probably its temperature. Hence for every degree of atmospherical resistance, there is some intensity of electrical repulsion proportioned to the square of the line P p, by which this resistance may be overcome, and the electricity may disperse itself into the surrounding atmosphere. And it is found by experience, that in the ordinary state of the atmosphere, it does not require any very great quantity of electricity to be imparted to a conductor for the production of this effect with a point of moderate acuteness.

The following experiments, in addition to some that have been adduced under the head of electrical light, are illustrative of this species of action.

(78.) *Exp.* Affix to the prime conductor of a machine, a pair of pith balls suspended by a fine silver wire, as described in art. 16, and let the conductor be charged with either electricity, the pith balls manifest the presence of this electricity by their divergence. If now we hold a pointed metal rod in the hand, presenting the point near to the conducting cylinder, but without touching it, the electrical charge is rapidly withdrawn, and the balls collapse. This experiment is rendered more striking, by repeating it with a rod having a large ball at the end, instead of the point, taking care that no spark pass from the conductor to the ball. In this case the divergency of the wires continues for a much longer time; therefore the metal ball has not absorbed the electricity with the rapidity that the points produced in the former experiments. It is quite immaterial whether we had presented the point to the conductor for the abstraction of electricity, or had affixed the point to the conductor for its dispersion. Hence in all cases, points and angular bodies absorb and emit the electric fluid, with much greater rapidity than those bodies which have obtuse or plane surfaces.

(79.) *Exp.* Let two cross wires AB, CD, fig. 51, be supported by means of a cap H upon a fine point at the top of an insulating stand, and made to communicate by a chain with the electrified conductor of a machine. Let each of the four arms terminate in a point bent in a similar direction with regard to the axis, as the figure represents. Each of these points will give off a current of electricity, which from the reaction of the resisting medium the air, will cause the system of points to revolve backwards with considerable rapidity.

Electri incline plane.

(80.) *Exp.* Fig. 52 is a representation of an elegant little experiment depending upon the same principle. Two wires A B, C D are stretched in the direction of a plane slightly inclined to the horizon, between four insulating pillars. Across these wires another wire is made to rest, having a cross wire at right angles to it with two bent points, as in the former experiment. This system is electrified by forming a communication with the prime conductor by means of a chain, as seen at A; and by the revolution of the bars, dependant upon the dispersion of electricity from the points, the transverse wire is made to roll up the inclined plane.

Electri orrery.

(81.) *Exp.* In fig. 53 A is a metal sphere, the interior concave surface of which rests upon a fine point surmounting an insulated stand. From the sphere A, an arm is extended, which carries upon a point at its extremity a smaller ball B, with a wire passing through it, which wire bears at one end another small fixed globe, and at the opposite end a bent point. There is also affixed to the arm passing from A to B, a point D extended in the plane of the horizon. Let electricity be communicated to this system by a chain as before. The dispersion of electricity from the point D, will cause the ball B to revolve round A; while at the same time the dispersion from the point, at the extremity of the rod C B, causes the ball C to revolve round B. This then, supposing A to represent the sun, B the earth, and C the moon, is called the electrical orrery.

See also Cavallo's and Singer's *Electricity*; Coulomb, *Mém. Acad. Paris*, 1784, 1785, 1786, 1787, and 1788; Biot, *Physique*; Libes, *Physique*; Fischer, *Physique*.

CHAPTER IV.

On the nature of electrical induction, and on the hypotheses of Du Fay, Symmer, and Franklin.

As far as we have hitherto proceeded in investigating the principles of the science before us, we have spoken of electricity developed by mechanical friction, and have given a pledge, that we will hereafter lay before our readers the other known sources of electrical excitation; but as a considerable proportion of important electrical apparatus depends upon the excitement caused by induction or influence, we devote the present chapter to an examination of this most interesting branch of our subject.

Electrical induction.

(82.) Let a horizontal cylindrical conductor B, fig. 54, with hemispherical ends, rest upon an insulating stand. Let there be suspended from it at different points, pairs of pith balls attached to fine wires or linen threads, and provide that the conductor shall have no free electricity by touching it with the hand. Carefully preserving its state of insulation, let it be brought near to an electrified body A, at the same time keeping the bodies at such a distance that no electricity may be transmitted from A to B by a spark. The following effects then take place.

1. The balls placed at the extremities of the cylinder diverge, and thus prove it to have become electrified.

2. This divergency decreases towards the middle of the cylinder, where a point may be found at which no repulsion is manifested.

3. This point of non-excitement varies its position upon the cylinder, according as this conductor is moved nearer to or further from the electrified body.

4. If an unelectrified pith ball, suspended by a silken thread, be made to approach the cylinder at

different parts of its length, the ball will be attracted in all positions, the neutral point before mentioned alone excepted.

5. But if the pith ball be previously electrified, it will be attracted by one end of the cylinder, and repelled by the other end; showing that the two extremities of the conductor are charged with the opposite electricities.

6. In fact, if we touch the two extremities of the cylinder, successively, with a small insulated conducting body, such as the proof plane, and examine the nature of the electricity which is removed at each contact, we shall find that at the extremity of the conductor nearest to the electrified body A, the electricity is of the kind opposite to that of A, while that at the other end of the conductor is identical with it.

7. If the cylinder be removed to a distance from the electrified body A, or if we remove the electricity of this body by touching it, all signs of excitement in the conductor immediately cease.

8. In this experiment, as far as the first six results are concerned, the body A, primarily electrified, loses nothing by the influence which it exerts. No part of its own electricity is transmitted to the cylinder, for if (by Coulomb's method) the intensity of its electrical excitement be measured, before and after the experiment, it will be found to have undergone no diminution, save that which is necessarily occasioned by the ordinary dissipation due to the contact of the air.

9. This uniformity of condition exists only when the body A is free from the influence of the insulated cylinder; for as long as the cylinder is near to the electrified body (this body being of conducting matter,) the electrical intensity upon its surface is different, as may be proved by experiment.

10. If, without touching the electrified body, we remove the conducting cylinder to a distance, and again bring it back several times alternately, the phenomena described appear and disappear without undergoing any alteration.

(83.) From the enunciation of these results, the following consequences are deducible.

1. Since the cylinder abstracts nothing from the electrified body, it follows that the two electrical principles are contained within its own substance, and are developed by the influence of the excited body. 2. Since the two electricities disappear as soon as the influence of the foreign body ceases, although these electricities are prevented by the insulation from escaping to the earth; it follows that their respective proportions are such that when left to themselves, they produce mutual saturation. 3. Lastly, that saturation is effected without their absolute destruction, because they reappear as often as the cylinder is subjected to the influence of the foreign electrified body.

Thus are we led to the recognition of this fact, that the principles of the two electricities exist naturally in all conducting bodies, in such a state of combination as to produce mutual neutralization. This then is what we call the natural state of bodies. We perceive that friction which appears a method of calling the electricities into existence, is only a process by which they are disengaged from their state of natural combination, the presence of either one then being rendered apparent upon the absorption of the other. Hence it is, doubtless, that we constantly observe that the substance rubbing, and the substance rubbed, manifest the opposite electrical states. In short, since the mere influence of an electrified body, presented at a distance, compels these two electricities to separate from each other, and to distribute themselves so that those of a dissimilar nature should be nearest to each other, and those of the same nature removed furthest from each other; to enunciate this fact, we must admit that *the electricities of the opposite kind attract each other, and the electricities of the same kind repel each other*, according to some certain laws which it is the province of the experimentalist to investigate.

There is, however, one phenomenon which may require further consideration. We remarked in the experiment last recited, that the electrical intensity of the body A underwent some change, which change was permanent only so long as the cylinder was presented to it. Now as the free electricity at the surface of any body acts at a distance upon the latent electricities of any other body, and destroys in part, at least, their combination, it is evident that these once set free, ought in their turn, to act upon the body which has set them free, and change the electrical intensity of all points in its surface, either by constraining the free electricity which is found there to assume some new distribution, or by adding to this electricity that which the body may furnish from the decomposition of its natural latent electricities, or, lastly, by producing both these effects simultaneously.

Further, the decomposition of the combined electricities in this case, is indispensably necessary to the production of attraction, for the attraction is diminished in proportion to the difficulty of this decomposition; and if the one be impossible, the other will cease altogether. To be convinced of this fact, take two silken threads of equal length, and affix to them two small spheres of equal magnitude, the one of pure gum-lac, and the other also of gum-lac, but covered by a surface of gold-leaf. Let these two suspended balls be placed side by side and near to each other, and bring near to them an excited glass tube or stick of wax. It will be seen that the ball having a metallic surface, upon which the decomposition of the combined electricities is easily effected, will be much more readily and forcibly attracted than the other. Upon the ball of pure gum-lac the effects only commence after a certain time, by the decomposition produced at its surface, and its electrified state continues even after the excited body has been removed. The first ball, although gilded, contracts also, by this process, a slight degree of permanent electricity, because the resin of which it is composed, becomes impregnated with that electricity which was developed at its surface; and both balls are assisted in this process by the action of the air, which tends to deprive them of that one of their combined electricities which is repelled from the primarily excited body, the action of the air being less upon the other electricity, which is, in a great measure, rendered latent by the presence of the extraneous fluid, which, by its approach, effected the decomposition. Hence it is a general remark, that insulated bodies which have been exposed for some time to the influence of an excited body, finally possess an excess of electricity, opposite in kind to that of the body, and this effect becomes apparent immediately upon the removal of the electrified mass.

(84.) As the results at which we have now arrived will form the constant subject of future application, it may be convenient to reduce them to a sort of theorem, under the following enunciation.

When an insulated conducting body B, fig. 55, in its natural state, is brought near to another insulated and electrified body A, the electricity distributed upon the surface of A, acts by induction upon the two latent and combined electricities of B, decomposing a certain quantity of them, proportional to the intensity of its action, and educing by this resolution the two constituent principles. Of these two electricities thus set free, it repels that of the same kind, and attracts that which is opposite in kind. The former is impelled to that part of the surface of B which is most distant from A, and the latter is brought to the side nearest to A. These two electricities, thus liberated, react upon the free electricity of A, and also upon its combined electricity, producing a further decomposition, especially if A be formed of conducting matter. This new separation brings with it a further decomposition of the combined electricity of B, and so on until the quantities of each elementary principle liberated upon the two bodies, shall be in equilibrium by the just balance of all the attractive and repulsive forces which they exert upon each other, by virtue of their identical or opposite natures. To calculate the law of distribution which will fulfil these conditions, will be the business of the second or mathematical part of this article.

For the present let us suppose this equilibrium established, and that we may continue our observations upon the resulting phenomena, let us return to the same arrangement of our apparatus represented in fig. 55. Further, in order to abridge the enunciation of facts, let us suppose that the electricity primarily imparted to A is vitreous. Then, if the conductor B have a cylindrical form, which has hitherto been our supposition, in order that the separation of the pure electricities may be more manifest, the part R nearest to A is charged with the resinous electricity, and the part V most distant is in the vitreous state.

In this condition of things, let the part V be touched by a third conducting body C, insulated, and in its natural state. Upon its removal, we find it charged with vitreous electricity. At the same time the threads placed at V upon the conductor A, approach each other, and the divergence of those placed at R is augmented. But if we remove B from the influence of A, or withdraw the electricity of A by touching it, B is found charged with resinous electricity alone.

These consequences arise simply from electrical induction, or influence exerted at a distance. Before the contact, the vitreous electricity of the body B, impelled to the point V, repels the vitreous electricity of A, and attracts the resinous electricity developed at R, and consequently weakens the actions of A upon R. By the contact of the third conductor we remove a portion of the electricity V, whereupon the action of A upon R becomes more powerful, because it is less counteracted. By virtue of its increased energy, it produces in the conductor B a fresh decomposition of combined electricity, of which the vitreous part is again carried towards V, and the resinous towards R. The total quantity accumulated at R is then, necessarily, more considerable than the other, because the latter alone has been weakened by the contact of C. Hence, when B is removed beyond the influence of A, the vitreous electricity V set at liberty is not sufficient for the complete neutralization of R, and from this excess the conductor B is found charged with resinous electricity. In consequence of this inequality under the influence of A, the divergency of the threads ought to be less at V than at R, which is conformable to observation.

Should it be required to carry this difference to its extreme point. Instead of touching the conductor B with an insulated body, which can at all times remove only a portion of the electricity V, let it be touched by any uninsulated conductor, thus allowing it to communicate for an instant with the earth. The whole of the free electricity collected at V will escape, the threads suspended at this point will collapse, and no longer give the least sign of electrical excitation, but the threads placed at R will diverge still more than in the previous case, and their divergence will not be diminished by again touching the extremity V. But by removing the conductor B from the influence of the body A, their divergence becomes still more considerable.

It is by no means difficult to comprehend the nature of this action. When V is made to communicate with the earth, all the vitreous electricity accumulated at that extremity is shared with the immense mass of the globe, and its electrical reaction becomes insensible; or, as may also be said, it decomposes the combined electricity of the earth, attracts resinous electricity by which it is neutralized, and repels the corresponding vitreous electricity which becomes distributed over the surface of the terrestrial sphere. In whatsoever manner we may conceive the matter, there is no longer any free vitreous electricity at V; therefore the vitreous electricity of A relieved from that resistance exerts a stronger action upon R. From this arises a further decomposition of the combined electricity of B, the vitreous part of which is dispersed in the same manner to the earth, while the resinous is accumulated at R, and so on until the attraction of A for R shall be completely satisfied. These decompositions, however, which in our reasoning we have supposed to take place in succession, that their progress might be more apparent, are produced instantaneously in metallic bodies, which may be considered as endowed with perfect conducting power, and it is from this cause that a single contact is sufficient to produce the complete effect. From what has been already said, we may readily comprehend why B, when removed beyond the influence of A, manifests a superabundance of resinous electricity, and why that excess is greater in the present than in the preceding case.

The experiments hitherto recited have all tended to demonstrate the action of the body A upon the conductor B; but the reaction of B upon A may also be made the subject of experiment, and with perfect confirmation of the results already obtained. The experiments upon B may also be varied by communicating to it at first a feeble charge of resinous electricity, and a series of actions will be manifested by the pith balls in perfect conformity with the explanation now advanced.

For the purpose of giving a definite form and name to our experiments, we supposed the body A to be at first supplied with vitreous electricity; but had the electricity been of the resinous kind, the same series of phenomena would have resulted, differing only by the opposite terms which the facts would then have required for their enunciation.

(85.) There yet remains another property which it is essential to prove, before we can obtain a complete expression for the law of electrical action. It is that, at any given distance, the attractive and repulsive powers are equal. This condition is, in fact, absolutely necessary, in order that when a body is in its natural state, the two combined electricities may produce no effect upon other bodies by influence or induction.

The following is an experimental proof of this proposition: Take two discs of smooth glass with plane surfaces; fragments of a glass mirror are well adapted to the purpose. Let A B, C D, fig. 56, represent these discs, each being four inches in diameter, and both affixed to insulating glass handles M and N; let there be also a pith ball suspended by a filament of untwisted silk. Rub the discs against each other, holding them by their insulating handles, and, without separating them, present them together to the suspended ball, no attraction is produced; but separate the plates from each other, and each, when presented to the ball, will now attract it. They have then both become electrified by the friction, and by presenting each in turn to another suspended ball charged with either known electricity, it will be found that the one plate has received a vitreous and the other a resinous charge. These electricities, however, do not manifest themselves when the discs are in contact, because as they reside upon the two surfaces which touch each other, the distance of all their points, from the electrical pendulum, is absolutely the same; and thus the opposite actions which they exert, tending to separate the combined electricities of the small ball are equal, so that the total result of their action is nothing. We may even modify the experiment so that this compensation shall be exhibited in its progressive state. For this purpose, after having separated the discs, we present the surface that has been rubbed, belonging to either of the planes, to the suspended ball, and allow of a short contact between the bodies. As soon as the ball has absorbed that small quantity of electricity which suffices for its volume, it becomes repelled and separates. Continue it in this state of repulsion by presenting it to the opposite face of the disc, fig. 57; for the electricity will act as well upon it through the substance of the glass. Next, let the second disc gradually approach the former, so as to place their electrified surfaces again in contact. In proportion as the distance between the faces diminishes, the repulsive force is found to diminish also, and the suspended ball gradually lowers itself towards the vertical line, and at last, when the faces are in contact, the system of discs acts only upon the ball, as any other body in a natural state does; but by again separating the discs, the ball may be made to elevate itself again as before. These two electricities, thus neutralized by their mutual contact (or at least very great proximity,) represent to us precisely the state of the combined electricities; with this difference only, that in conducting bodies they are united to each other by their force of combination alone, and may be set at liberty by the distant influence of either free electricity; instead of which, in the discs before us, each electricity is detained by the non-conducting power which the glass opposes to the freedom of its motion. For this reason the experiment now described will succeed equally with discs of gum-lac, or of sealing-wax, or even with one disc of such a substance, and one disc of metal; but it cannot succeed with two metallic discs, because in this case no resistance is offered to the motions of the electricities which are disengaged by friction, and consequently they reunite again as fast as the friction produces their momentary separation.

General law.

(86.) Having now established on the basis of experiment only, a general series of facts, upon which we conceive we may (at least as far as these facts go) attempt the reduction of electrical phenomena to some general scheme of action, we must, in some degree, retrace our steps, and collect the enunciations of such laws as our experiments have afforded us.

We have seen that whenever electricity is developed, two distinct principles are separated from each other, and may be each submitted to experiment separately, as in the common machine, (5,) or the separated discs (85;) also, that the two may be suffered to reunite as by Nairne's machine, (42,) and the two discs both of metal (85) thus reproducing the state of natural equilibrium, or no excitement; or else, that they may be retained out of their state of native combination, but rendered latent by their mutual proximity, (85.) It has also been shown, (70,) that whenever either of the electricities is present in a conductor, it arranges itself according to certain laws, but such that the whole mass of fluid may be situate at the exterior surface of the conducting body, (71,) to which it seems to be confined by the pressure of the air; and this supposition receives still further confirmation from the fact of all the electricity being dispersed, when the pressure of the air is removed under the exhausted receiver. Hence we infer that the molecules of the same fluid are mutually repulsive of each other.

Observing also the apparently perfect mobility with which the two fluids traverse conducting bodies; approach to or recede from each other; enter into intimate union, or instantaneously submit to a separation, without losing in any degree their original properties, we are compelled to admit that the most probable idea we can form of their nature, is to regard them as fluids of perfect fluidity, the molecules of which being endowed with attractive and repulsive properties, arrange themselves in such bodies as allow of their free motion, in such a manner that all the interior and exterior forces which act upon them shall be in equilibrium.

The repulsion of two masses of the same fluid disposed in movable conductors, as manifested by the separation of these conductors, is equal in intensity to the attraction exerted by two equal masses of different fluids similarly circumstanced; and therefore it appears that the molecules of the same fluid repel each other, with a force equal to that with which they attract the molecules of the other fluid; and it is yet to be shown that the mathematical law of these attractions and repulsions, is that of the inverse square of the distance. The mutual actions of the two fluids has also been strongly exemplified in the recent paragraphs of our article, wherein all the phenomena of influential or induced electricity are laid open.

Our general proposition may then be thus enunciated, *Each of the two electrical principles has the properties of a fluid; the molecules of which enjoy perfect mobility, are mutually repulsive of each other, and attractive of those of the other fluid, with forces varying according to the inverse square of the distance. And at equal distances the attractive and repulsive forces are equal to each other.*

It is not contended that the experiments hitherto advanced, will prove the whole of these propositions with perfect accuracy, but it is necessary thus to collect and arrange the conclusions to which these experiments justly lead; in order that we may have some definite system, upon which our future explanations may be founded; and it is but by a slight anticipation that we have taken in the whole of these essential elements of our law, since in a future division of this treatise, devoted to theory alone, every branch of our proposition, which yet requires such support, will be brought forward with rigid mathematical demonstration.

Symmer and Du Fay.

(87.) For the sake of consistency, we have throughout this article adhered to a system of explanation founded upon the hypothesis of Symmer, respecting the nature and action of the two fluids originally discovered by Du Fay, enriched and confirmed as this theory has been by the researches and discoveries of later years. In the historical introduction prefixed to this article, we have stated our reasons for assigning the merit of this hypothesis to Mr. Symmer; and although in an article like the present, which can only be considered an outline of electrical science, we feel bound not to become warm partisans of any particular hypothesis, because our limits will scarcely permit us to examine those difficulties which attend every view of the subject; yet we must confess that between the theory of one fluid proposed by Franklin, and the supposition of two coexistent fluids as advanced by Symmer, the advantage appears to us greatly on the side of the latter.

The hypothesis of two fluids has now, doubtless, the greater number of partisans; but in justice to those who have embraced, and who still adhere to the views of Franklin, we will endeavour to present a short abstract of his theory.

Franklin's theory.

(88.) In this theory only one electric fluid is supposed to exist. It is considered to be material and to possess the properties of an elastic fluid. It is also supposed to attract and to be attracted by all other matter.

The attractions of different substances, for the electric fluid are different, as also those of the same substance in different states, and under different circumstances; so that the quantity of electricity naturally existing in given quantities of different substances may be unequal; and the same body may, under the circumstances of its combination with other matter, attract more or less than when alone; but its original attraction will be restored by destroying the artificial combination.

When the attraction of any substance for electricity is equal to the quantity of electric fluid it contains, that substance exhibits none of the phenomena of excitation; but these are immediately produced when there is either more or less electric fluid than is adequate to the saturation of the existing attraction. If there be more, the electrical signs will be positive, (vitreous,) if less they will be negative, (resinous.)

"Electrical excitation may then be thus effected: the bodies employed have each a certain quantity of the electrical fluid, proportionate to their natural attraction for it, this they retain, and appear unelectrified, so long as they remain in their natural state. Now if two such bodies are brought in contact, their natural attractions are altered, one of them attracts more than in its separate state, and the other less; the electric fluid diffuses itself amongst them in quantities proportionate to their relative attractions, and they consequently appear unelectrified. But if they are suddenly separated, the new distribution of the electrical fluid remains, whilst the original attractions are restored, and as these are not equal to each other, the bodies will appear electrical: that whose natural attraction was increased by contact, having received an addition to its quantity of electric fluid, will be positively electrified; and that whose attraction was lessened, having lost a portion, will be negative.

"Take, as an instance, the electrical machine: let the attraction of the cushion for the electric fluid be represented by 20, and that of a similar surface of glass by 30, the sum is 50. Bring the bodies in contact, their attractions alter; that of the glass becomes 40, and that of the cushion is reduced to 10, the sum of these is still 50; the natural electricity therefore, though unequally distributed, is still equal to the sum of the attractions, and does not appear; for the cause of its unequal distribution, (the contact,) is still active. Separate the glass from the cushion, its original attraction of 30 will now only operate, but it has acquired 40 of electricity by contact with the cushion; the glass is therefore positive with a force equal to 10. The cushion will now also have its original attraction of 20, but its electricity amounts only to 10; it is, therefore, negative with a force equal to 10. And here is seen the reason why positive and negative bodies act more powerfully on each other than on indifferent matter, for their mutual difference is often twice as great as their individual; since if the latter be 10, the former may be 20.

"The effects now described continually recur during the revolutions of the cylinder, every part of which is successively brought in contact with the cushion, and passes forward with the electricity it thus progressively acquires. The silk flap may be considered as a continuation of the rubber, which, by partially maintaining the altered attraction of the glass, counteracts the tendency of the acquired electricity to pass back into the cushion. The surface of the glass where it passes from beneath the silk flap has not this compensation; hence the acquired electricity is there uncombined, and has a tendency to diffuse itself amongst the surrounding bodies: the conductor, with its row of points, is the nearest reservoir, and into this it passes, and the conductor becomes thereby *positively electrified*. During this process the cushion and its attached conductor constantly furnish electricity to the glass, and *they* are consequently negative in the same degree; but they have only a *limited* surface, and a *certain quantity* of natural electricity, and,

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if perfectly *insulated*, can furnish only a definite portion; but if they are connected with the ground, whose surface is comparatively *unlimited*, they operate upon an extensive store, to the supply of which there appears no assignable bound. It is for this reason that the electricity of either conductor *separately*, is more apparent when the opposite one is *uninsulated*." Singer, *Electricity*, p. 61.

The above outline of the hypothesis of Franklin is not precisely in the state in which it was left by its illustrious proposer; neither can we be certain that all those who contend for the existence of but one electric fluid would subscribe to every part of the doctrine thus laid down, but we have considered that it would be the fairest course, and one in which we should be least liable to the accusation of partiality, to bring forward these passages as the most recent explanation with which we are acquainted of the opinions of an author on this side of the question. As far as the hypothesis is required to explain all the common phenomena of electricity, such as the attractions of bodies, and the charges communicated to jars and batteries, either of these two celebrated theories will be found sufficient; but we confess it does not appear to us that Franklin's hypothesis is adequate to the satisfactory explanation of several of the phenomena of influential or induced electricity.

Expe-
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proofs.

The following, whatever they may prove, are experiments of great beauty, and therefore claim a place in our article. According to our principles of arrangement, they ought it is true to fall under the first and fifth chapters, but as they are specifically brought forward by Mr. Singer in proof of Franklin's hypothesis, we are willing to insert them at once, in order that we may not have to return to this subject hereafter.

(89.) *Exp.* To the conductor of a machine so arranged as to be charged with negative (resinous) electricity, present a pointed metal rod, held in the hand, and in a darkened room. A cone, formed of rays of light, will be seen, having its vertex at the point, and its base towards the conductor; but if a similar point be presented to a positively electrified body, instead of the cone of light there will be seen a brilliant star, at the extremity of the metallic point. The light in these experiments is considered to indicate the course of the electric fluid. The point is a sort of pipe capable of emitting or receiving it. The negative conductor is supposed to have a deficiency, and the point presented to it is illuminated by a diverging pencil of rays, which indicates that the cause of that light moves from the point to the negative body. The positive conductor is supposed to have an excess of electric fluid, and the point presented to it is merely illuminated by a globular spot of light; an appearance that may be conceived to attend the entrance of a subtle fluid into it.

Reversing the experiment by connecting the points with the conductors respectively, the converse series of phenomena is produced.

(90.) *Exp.* "Take the transfer plate of an air pump, and affix to its centre, by a wire three inches long, a brass ball one inch in diameter, fig. 58, connect a similar ball by a sliding wire to the top of a receiver, and place this over the transfer plate, so that the one ball may be vertically over the other, and at the distance of about one inch. Exhaust the receiver accurately, and then connect the plate with the negative conductor, and the upper wire and ball will be positive. Upon turning the machine, a torrent of beautiful purple light will pass from the positive to the negative ball, on which it breaks and divides into a luminous atmosphere, entirely surrounding the ball and stem, and conveying most strikingly the idea of a fluid running over the surface of a resisting solid, which it cannot enter with facility. No appearance of light occurs on the positive ball, but the straight luminous line that passes from it; but if it be rendered negative, and the lower ball positive, these effects are entirely reversed." (Singer.)

(91.) *Exp.* Fig. 59, "represents two hollow metal balls, about ¾ of an inch in diameter, insulated upon separate glass pillars, by which they are supported, two inches apart; the upper part of each ball is indented, so as to form a small cup, in which a fragment of phosphorus is to be placed. A small candle or lamp has its flame situated midway between the balls; one of them is connected with the positive and the other with the negative conductor of the electrical machine by means of a wire. When the balls are electrified the flame is agitated and inclines to that which is negative; this it soon heats sufficiently to fire the phosphorus, whilst the positive ball remains perfectly cold, and the phosphorus unmelted. If the connecting wires be now reversed, so that the ball which was before negative shall become positive, and that which was positive be rendered negative, the phosphorus in the latter will soon take fire. So that electricity passes from the positive to the negative, and transmits with it the heat of any intervening ignited body."

Such at least is the reasoning of Mr. Singer, but we shall in course of time have to advert to this experiment, for the purpose of showing that it may admit of a very different explanation; for the present only remarking, that this solution takes for granted that the electric matter "*transmits with it*" the matter or property of heat, and therefore must have an attraction for it, an assumption which other experiments tend to disprove.

(92.) Some of the most important arguments against Franklin's hypothesis may be thus briefly stated, much in the form under which they have been brought forward by M. Biot.

1. In reasoning upon one electric fluid only, its molecules are admitted to be mutually repulsive of each other; but as it is proved by experiment that bodies in their natural state exert no electric attraction upon each other, it follows upon this supposition that an attraction exists between the electric molecules and the particles of ordinary matter. It has been proved by elaborate calculation, that this condition would not suffice for the production of equilibrium, and that a further assumption must be made, that the particles of bodies exert a repulsive [illegible] upon each other, sensible at great distances, like [illegible] electrical actions themselves. Analogy is [illegible] any such supposition. For instance, in the [illegible] universe, attraction alone is capable of [illegible] the motions of the heavenly bodies, and the [illegible] position of any such repulsion is contrary [illegible] nary phenomena of nature. It is true that [illegible] of Franklin his principle was sufficient [illegible] all the experimental phenomena known [illegible]; but when Æpinus had undertaken [illegible] matical investigation of all the [illegible]

tion, he perceived the necessity of calling in the aid of this supposed repulsive force, to make his demonstrations accord with the facts he intended them to elucidate.

Opposed as this condition is to the acknowledged nature of things, if we were to admit it solely for the sake of connecting together electrical phenomena, we might arrive at a conception of their dependence, and even be enabled to foretel their appearances; not indeed in quantities and numbers, but under those general conditions which depend upon a displacement of the one electricity. Thus, for example, we might explain the attractions, the repulsions, of electrified bodies; and even the developement of electrical properties from bodies in their natural state by the distant influence of another electrified body. But it does not appear that it would be possible to explain in the same manner why, conducting bodies acting by attraction upon the molecules of the electric fluid, the electricity should divide itself between their surfaces according to certain ratios, entirely independent of their chemical composition, and determined only by their dimensions as we find to be the case; nor yet why the negative state, which is according to this system only a privation, an absence of electricity, should ever be developed alone at the surface of these bodies, and establish itself at each point of that surface, according to the rigorous hydrostatic laws which a real fluid would follow, if all its molecules were mutually repulsive of each other, according to the inverse square of their distances. Still less could we, upon this hypothesis, foresee or explain why, when two unequal spheres of conducting matter are removed from contact, there should be developed around the point of contact, and always upon the smaller, signs of an electrical state contrary to that of the total mass, be it positive or negative; while, on the other hand, the necessity for this developement, its limits, and its constancy upon the smaller sphere may be foreseen with the greatest ease, upon the theory of two fluids; nay, may even be calculated in all its most minute particulars with a surprising degree of exactness. (See part ii. of this Treatise.)

Applications of induction.

(93.) Let us now proceed to apply this hypothesis of two fluids, in explanation of those effects which our instruments have already laid before us. As it is found possible to obtain electricity, in some way or other, from all bodies that can be properly submitted to experiment, we are led to infer that it is an universal property of matter. We suppose that in every particle of matter a portion of each electricity naturally resides. That in the ordinary state of that particle there is an equal quantity of each fluid present, producing mutual saturation; and that therefore when we say no electricity is present in a body, we mean that there is no *free* electricity that can be recognised by its effects or properties. Suppose now that we can by some means effect the decomposition of this natural electricity, and that we can remove one of the kinds from the particle, it is evident then that the remaining electricity being no longer saturated, is called into a state of activity, and exerts the properties that are natural to it.

In the ordinary electrical machine we may at any instant suppose the developement of electricity to take place by the mutual friction of the rubber, and an equal surface of the cylinder, or plate. The vitreous electricity will be carried forward with the cylinder, to the surface of which it is confined by the oil silk, and if there were no conductor to receive it, a part would be dissipated in the surrounding air, and a part would return again upon the glass to the cushion. At the same time the rubber receives or retains the resinous electricity set free by the decomposition, and if insulated soon acquires such a charge of this electricity that its repulsive intensity either prevents further decomposition, or drives off a quantity sufficient in a great measure to again combine with and neutralize that vitreous electricity which is produced by the continued action of the machine. But if the rubber communicate with the earth, this excess of resinous electricity is shared with that body, and the effects on this side of the machine continue to go on as at the first instant of its action. A similar accumulation of electricity upon the *insulated* prime conductor, when it has become charged to its utmost possible extent, will on similar principles produce a similar diminution or cessation of effect. Hence we arrive at the full explanation of the necessity for allowing the rubber to communicate freely with the ground, when a considerable quantity or a constant supply of vitreous electricity is required at the prime conductor; and vice versa.

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(94.) The action of the prime conductor itself will also require some portion of our attention in applying the principles of the chapter before us. It is not to be considered as merely a receptacle or channel through which certain electricity which enters at the points is to proceed; but it, together with its system of points, may claim the merit of a more active species of service. At the edge of the silk flap we have clearly shown that there must be a torrent of electricity ready to escape to the nearest conductor which its own repulsive intensity will enable it to reach. This portion will then naturally make for the points, and be conveyed by direct transmission to the prime conductor. But the accumulation of this electric mass at the edge of the silk cannot take place without also acting by induction upon the natural electricities of the conductor and its points; the electricity of which we now speak being vitreous, will attract towards the points of the prime conductor a portion of resinous electricity dependent in quantity upon the intensity of the action of the machine; and as this intensity at so small a distance is very considerable, and the points are of all others the form most favourable for the emission of electricity, a portion of resinous electricity is constantly issuing from the conductor to combine with the vitreous electricity arriving at the edge of the silk. The appearances presented by the points of an electrical machine in a darkened room, will afford a beautiful illustration of this system of effects.

Electr scope.

(95.) In art. 51, we described the process for communicating either electricity to Haüy's electroscope, by employing the principles of induced electricity, and it is obvious that in a similar manner we may, with any excited body, communicate to any electroscope a charge consisting of either electricity at pleasure. Either we may impart by direct contact some portion of the electricity from the excited body, in which case the charge is similar; or we may by the distant influence of the excited body decompose the natural electricity of the electroscope; and having removed the similar electricity which is acted upon repulsively, upon withdrawing the excited body, a charge of dissimilar electricity remains upon the instrument.

(96.) It may almost be considered a superfluous task to enter upon the subject of what the early experimentalists termed *electrical atmospheres;* but as the principles we have so recently brought forward will afford a ready explanation of this phenomenon, and as the subject does not appear to have been well understood, even in some recent treatises of great merit upon electricity, we feel it incumbent upon us to devote a few lines to the elucidation of this subject.

The idea of the electric effluvium forming an atmosphere around an excited body, is perhaps to be traced among the theoretical views of the earliest practical electricians. The writings of Otto Guericke clearly contain a supposition of this kind, and the Florentine academicians attempted to submit the arrangement of this atmosphere to ocular inspection, by bringing a piece of excited amber near to a volume of smoke, so that the visible particles which constituted the smoke were attracted by the amber, and formed a stratum around the excited body, so long as its electrified state continued permanent. Dr. Franklin improved upon this method, by placing heated iron plates under electrified conductors, and then scattering upon the plates small fragments of resin. The smoke as it rose from the plates arranged itself in visible strata around the electrified surfaces, presenting numerous beautiful appearances. These researches of Franklin were followed up by MM. Wilcke and Æpinus; and it is but due to this latter most acute electrician to remark, that as far as the explanation of all these phenomena depends upon electrical induction, he arrived at a just theory of the matter. Beccaria and Canton also published several curious memoirs on this subject. It was maintained by some that there actually existed an atmosphere of electricity surrounding the excited body; but Æpinus justly contended that the effects which appeared to indicate the presence of such an atmosphere were to be ascribed to electrical influence; and that the supposed extent of such an atmosphere was in fact only the sphere of action of the electricity arranged upon the excited body: but at the same time he mingles with these correct views some portion of error in supposing that the air is electrified throughout this sphere of influence, when in fact it is much more simple to leave the air (in this sense) out of the question, and to consider the particles of smoke only as so many small bodies, possessed of freedom of motion, and therefore attracted towards an electrified surface.

It would be an unprofitable task to enter upon a minute examination of M. Canton's views, which were in principle deduced from the explanations of Æpinus, but which contain also some erroneous opinions respecting the part performed by the air in the production of these phenomena. Canton found that two unelectrified pith balls placed within a small distance of an excited body, such as either a glass tube or a stick of wax, diverged, from having become charged with an electricity opposite to that of the excited body. And generally that any unelectrified substance placed within the electric atmosphere (sphere of action) of any excited body, obtained a charge of the dissimilar electricity. These facts admit of a ready explanation, upon the principles of electrical induction, and in taking leave of this subject we have only to remark that the views of M. Æpinus appear to have been much more philosophical and accurate than those of the preceding or contemporary experimentalists, in this field of research.

Arrangement.

(97.) In considering the arrangement or distribution of the electric fluid upon conducting bodies in contact, (art. 76,) we were unwilling to pursue those investigations further at that time, from their intimate connection with the new distribution which takes place the instant that contact is destroyed; and it was impossible to enter upon that part of our task without a previous acquaintance with the phenomena of induced electricity. The faint outline which we propose now to give of these arrangements is imperiously called for by the numerous consequences deducible from them, and which must all be taken into account by the accurate practical electrician. We are therefore for the present again confined to the enunciation of certain facts presented to us by experiment, which it will require all the ingenuity of the most refined theory fully to account for.

If two spheres of equal magnitude, composed of conducting matter, be electrified and placed in contact, the free electricity will be equally divided between them; and it may be proved by delicate experiment that no free electricity resides at the point of contact; this also is conformable to theory. If now the two spheres be separated beyond the limit of the sensible influence of each other, the free electricity will be found of equal intensity upon each; or, in other words, the two spheres have during their contact divided the electricity equally between them. In the case of unequal spheres, it may also be proved by experiment, and accounted for by theory, that after their contact the total quantity of electricity carried off by the smaller sphere, is less than that which remains with the larger sphere; but according to a law depending upon the ratio of their diameters, such that the stratum of fluid retained upon the smaller sphere is of greater thickness than that upon the larger sphere.

Thus far we speak of the ultimate arrangement of the fluid, when the two bodies shall have been removed beyond the sphere of their mutual influence upon each other; but let us now take into account the effect of induction, and trace the progress of effects upon the spheres during their gradual recession from each other.

Let there be two unequal spheres, both vitreously electrified, of which fig. 60 may represent a vertical section. The bodies being so arranged that their centres may move along the same horizontal lime; when the points A, *a*, are in contact the electricity is unequally divided between them, and arranged at their surfaces, but is absolutely nothing at this point of contact. At the instant of their separation, however, this arrangement is destroyed, a part of the combined electricity of the smaller sphere is decomposed, and the resinous portion thereof, being the contrary to that of the larger sphere, is attracted to the point *a*, by which the spheres formerly were in contact. By gradually increasing the distance of the spheres, this effect is diminished, and at length a position may be found, at which the resinous electricity of the smaller sphere developed by induction, and collected at the point *a*, is equal to the vitreous electricity at the same point, according to the state of its distribution over the sphere, and thus a second time the point a is found without a single molecule of free electricity. The distance at which this effect takes place, depends upon the ratio of the radii of the spheres, and the quantity of electricity at first communicated to the system. By all further separation beyond this limit, the electricity remains of the same nature, throughout the whole surface of the smaller sphere, being the same which it possessed at the moment of contact. These phenomena are peculiar to the smaller of the two spheres, whatever be the quantity of electricity communicated to the system. Upon the larger sphere, and upon every part of it, the electricity is at all times of the same kind as during the contact of the bodies. (See part ii. for the mathematical investigation of these properties.)

The laws by which these effects may be foreseen and calculated, have even been extended to the same problem in its most general form, where the spheres are not first brought into contact, but are charged with any known quantities of the same or opposite electricities.

Discharge or spark.

(98.) Under whatsoever conditions the experiment is commenced, if there does not exist upon the two spheres that exact ratio between the two electricities in quantity and kind, which contact would have established, according as they gradually approach each other, the thickness of the electric strata at the points nearest to each other upon the two surfaces becomes greater, and increases as their distance diminishes. The same effect takes place with regard to the pressure exerted by the electricity against the lamina of air interposed between the two bodies. Finally then, this pressure will overcome the resistance of the air, and the fluid escaping under the form of a spark or otherwise, ought to pass before the contact from one surface to the other. The fluid thus accumulated previously to the discharge is of opposite kinds, and of nearly equal intensities upon each of the spheres.

If at the first opposite electricities be communicated to the two spheres, the charge which arranges itself upon each to form the spark, continues to consist of portions of these opposite electricities. But suppose both spheres to have received the same kind of electricity, vitreous for example, then during their approach a decomposition of the combined electricity takes place upon that sphere which contains less of the vitreous fluid than it ought to have during contact; the resinous electricity resulting from this decomposition is determined towards the point where the spark is preparing; and at the same time the other sphere, which has already more vitreous electricity than it ought to have after contact, remains vitreous throughout.

Other and more complicated cases of electrical action dependent upon these principles, and connected with this series of illustrations, have been devised as trials of the theory; but as that is not our present object, we limit ourselves to an explanation of such cases only as occur in experimental electricity.

(99.) Perhaps it may be thought that we have even carried these apparently intricate details further than was absolutely necessary for our practical purposes; but it is only at this part of our progress that we find ourselves in possession of sufficient acquaintance with the phenomena of electricity, to explain a result which we could not avoid meeting with in the outset of our compilation. Why did not the ball mentioned in art. 2, as soon as it had received a portion of the same electricity which had been developed upon the glass tube, manifest a spontaneous repulsion? To answer this question, we must minutely consider all the circumstances of the case. The excited glass tube may be supposed to be studded with molecules of vitreous electricity, fixed immovably upon the particles of its surface. Upon presenting this excited tube to the suspended pith ball, its natural electricity is decomposed, and as we have shown, in art. 17, attraction must take place, the ball then comes in contact with the tube. During this process, the side of the ball next to the tube is charged with resinous electricity, and as it is formed of conducting matter, a sufficient quantity of the resinous fluid is immediately supplied to neutralize the one or more molecules of vitreous electricity found upon the glass exactly at the point of contact. When this neutralization is completed, there still remains the attraction of all the more distant molecules of vitreous electricity disposed upon the surface of the glass, where they are fixed, and therefore cannot proceed to the ball for the purpose of neutralizing the stratum of resinous electricity which they have attracted to its proximate surface. Hence, then, it is necessary either to let the ball move along the surface of the glass, so as to pick up, as it were, a sufficient number of molecules of vitreous fluid to saturate all its induced resinous fluid, and to produce an actual and immediate repulsion between the two bodies; or else by shaking off the ball from the tube, and then gradually approximating the bodies, there may be a distance found at which the repulsive force exerted between the fluid upon the tube, and the fluid imparted to the ball is manifest; at least, if the disparity of excitement be not too great, a circumstance that ought to be guarded against.

(100.) After these ample, and as we trust satisfactory details, it scarcely can be necessary to enter minutely into the same analysis of all the effects produced in the cases of balls of conducting matter mentioned in art. 17. We there asserted that the effects produced by electrical induction would tend to aid the forces under examination, and such, upon a just review of the matter, will be found to be strictly the case.

For several of the illustrations in this chapter we are indebted to the admirable *Traité de Physique* of M. Biot, vol. ii.

CHAPTER V.

Application of the principles of induction to the artificial increase, or quantitative accumulation of electricity.

In the first three chapters of this treatise, electrical phenomena have been described and reasoned upon under the hypothetical assumption of two fluids, ever resident in all bodies; and these chapters were devoted to an examination of the effects produced by the motions of the identical communicated or transmitted molecules of these fluids. The subsequent chapter brought before us the agency of a given quantity or intensity of electricity, in enabling us by its influence to develope in other insulated conducting bodies a certain portion of free electricity, dependent upon known laws arising from the magnitude, form, and relative position of the bodies. In the chapter now before us, we proceed to show in what manner, by a practical application of these principles, we may be enabled, by having at command a sort of reservoir capable of retaining a given quantity of either free electricity, to obtain from the earth and to insulate an equal quantity of the dissimilar fluid, which is the principle of the *electrophorus*, or by similar means to determine towards any given part of an insulated system of bodies a greater proportion of electricity than that part would otherwise acquire, which is the effect both of the *condenser* and the *electrical jar* or *battery*. The following then will form the principal matters contained in the three sections of this chapter.

§ I. The electrophorus.
§ II. The condenser, and its applications.
§ III. The electrical jar, and battery.

§ I. *The electrophorus.*

(101.) The electrophorus was invented by the celebrated Volta, about the year 1774, and from the principles of its action we trust we shall be enabled fully to establish its claim to a place in this part of our treatise. To be as explanatory as possible, let us analyze certain effects depending upon the properties of induced electricity, before we proceed to an examination of the instrument itself.

It has been shown, that if we bring any uninsulated conducting body near to an electrified and insulated conductor, and then suddenly insulate the former body, and remove it beyond the sphere of action of the electrified conductor, we shall find that it has acquired a charge of free electricity. If a disc of metal, furnished with an insulating handle, be brought near to the electrified conductor of a machine, (taking care that no spark pass between the bodies,) and then again removed, it will be found upon trial to remain in its natural unexcited state; but if at the same time that the disc is near the conductor, it be touched with the finger, so as to form a communication with the earth, and then withdrawn from the presence of the electrified conductor, it will be found to have acquired a charge of free electricity dissimilar in nature to that of the conductor.

Next, let a metal disc A, fig. 61, supported upon an insulating stand, receive a spark from the prime conductor of an electrical machine; it may then be employed to electrify another similar disc B, without contact or spark, by the means pointed out in the two former experiments; and as the second disc is electrified by induction, without abstracting one particle from the electricity of the first disc, the experiment may be repeated an indefinite number of times; or, at least, so long as the disc A is able to retain its electricity. The only obstacle to this being the dispersion which is continually going on from the contact of the air.

To analyze the process that takes place in these discs, let the lower disc A be made to communicate by a wire with an insulated pith-ball electrometer, as seen in the figure. On the communication of electricity by the spark the balls will diverge, but in proportion as we bring near the uninsulated disc B, the divergency of the balls and wires will diminish, until at last the electricity which before rendered them mutually repulsive seems to be destroyed. But it is in fact only rendered latent, for as soon as the disc which communicates with the earth is again removed, the divergency of the wires is reproduced to an extent as great as before. In this case the decomposition of the natural fluid contained in the upper plate increases as the plate approaches towards the electrified body, and consequently its electrical charge augments in proportion as the distance between the two discs decreases, and would arrive at a maximum at the instant of that distance becoming nothing. The obtaining this maximum effect is however prevented by the passage of a spark between the bodies, for which reason it is necessary to interpose a thin lamina, of some substance not readily permeable to the electric fluid, such as a plate of glass, or a stratum of resin.

By the application of this method, we arrive at the construction of the *electrophorus*. Let the lower plate be supported by an insulating stand as before; upon its upper surface place a thin plate of glass, and let the upper plate of metal also be furnished with an insulating handle. If then electricity be communicated to the lower plate by a spark, we may at will place the upper plate upon the glass, touch it for an instant with the finger, and then having raised it by the insulating handle, it will be found charged with an electricity the opposite to that of the lower plate. This process may be repeated indefinitely.

Retaining these principles in view, we may construct an electrophorus, such that the thickness of the insulating plate may be indefinitely small, by forming the lower disc of glass or resin, either of which substances may be excited by friction, and retain their electricity so forcibly, that the upper metallic disc may be placed immediately upon the surface of the excited disc, without receiving by communication any sensible quantity of electricity, while at the same time, from the proximity of the metal which is to be electrified by induction, to the electricity resident upon the glass or resin, the most powerful effects are produced.

(102.) Such is in fact the electrophorus of Volta. Let B B, fig. 62, be the upper surface of a plate of resin rubbed with a cat-skin, by means of which resinous electricity is developed. Let a metal disc A A, suspended by an insulating handle, be gradually brought near to the resinous plate, and let a wire pass from the upper part of the metal plate to an insulated pith-ball electroscope. In this case the balls will be found to diverge with resinous electricity. By employing a plate of glass instead of resin, the converse effect is of course produced. Hence, generally the electricity of the upper surface of the metallic plate, as manifested by the pith balls, is of the same nature with that of the lower plate excited by friction.

If the upper disc be placed in contact with the excited plate, and again removed, as all the effects that can be produced arise from the decomposition of its natural electricity, and as from the insulation neither electricity can escape, upon again withdrawing the disc, these electricities recombine, and the metal returns to its natural state. But if a considerable time elapse before this removal and recomposition take place, some portion of that electricity which has been repelled towards the pith-ball electrometer, will be dissipated by the contact of the air, and an exact spontaneous saturation cannot again take place.

From the preceding analysis of effect, it is evident that in order to give to the metal disc the utmost charge of which it is susceptible, we must open a channel for the escape of the resinous electricity which is repelled; and this is done by touching the disc for a moment with the finger, and thus connecting it with the ground.

As yet we have considered the surface which has been submitted to friction, as if it alone existed in a state of perfect insulation in free space; but in reality the resinous cake of the electrophorus is a plate of appreciable thickness, and hence a new series of phenomena will arise. The electricity developed at the surface which has been rubbed must act by influence upon the natural electricity of the second surface also, and of all other contiguous bodies, in the same manner as it acts upon the movable plate of metal; and this complicated action will modify the absolute quantity of electricity which is to be rendered latent during the contact.

Let us then consider the electrophorus of Volta as it is actually constructed. Let B B, fig. 63, be the resinous cake, which it is usual to have cast in a mould of tin D D, so that in fact all the points of the under surface of the plate have an immediate communication with each other. Previously to exciting it by friction, let the apparatus be placed upon an insulating stand, and let the tin case communicate with the balls of an electroscope. Beat the upper surface of the resinous plate with a piece of dry fur, and the balls of the electroscope will diverge with resinous electricity. Evidently then this effect has been produced by the electricity developed at the upper surface, which has decomposed the natural electricity of the case, and attracted the vitreous portion, at the same time that it repelled the corresponding resinous portion to the electroscope. Next, touch the case, the resinous electricity is abstracted, and the vitreous remaining latent, undergoes no diminution, but in consequence of the escape of the resinous portion, the threads collapse. If now we gradually bring near the superior metal disc, touching it at the same time with the finger, so that it may communicate with the earth, the free electricity of the resin acting upon the natural combined electricity of the metal plate, repels its resinous electricity to the earth, and attracts its vitreous portion towards that surface which is nearest to the resinous disc. This vitreous electricity, acting in its turn, by attraction upon the resinous electricity of the surface rubbed, and also by repulsion upon the vitreous electricity collected upon the tin case, evidently tends both ways to diminish the force by which this vitreous electricity is rendered latent, and some will therefore be set free, causing the balls again to diverge, but with vitreous electricity, and this divergence will increase in proportion as the metal disc approaches more and more nearly to the resinous plate. But since this vitreous electricity of the case tends to repel the vitreous electricity with which the upper plate is to be charged, we must make the tin case communicate with the earth, by which means it is reduced to its natural state, and the electricity of the upper surface of the resin renders latent the maximum quantity of vitreous electricity upon the metal disc A A, just as if the tin case did not exist at all.

(103.) In repeating all these experiments with rigid accuracy, the influence of the air in producing a gradual dissipation of those electricities which are not rendered latent must be taken into the account; but if we consider an electrophorus left with its plates in contact, we shall see no reason to suppose that its effects will be much if at all diminished by the access of the air; because all the resinous electricity of the lower plate is rendered latent by a saturating quantity of vitreous fluid, which has been attracted towards the lower surface of the upper plate, by means of its communication with the earth. Hence it is found that a well-constructed electrophorus will remain for months in full energy, but in process of time the two electricities of the plate and the resin do actually enter into combination, and undergo a mutual and permanent saturation.

(104.) It is even possible to form an electrophorus such that the resinous plate may receive and retain a charge of vitreous electricity. For if two resinous disc be taken of equal magnitude, and one of them be excited by beating and rubbing it with a cat-skin, we know that it will become resinously electrified, and that consequently it will be capable of developing a charge of vitreous electricity in the movable metal disc of an electrophorus. Having thus charged the movable metal disc, let it be placed upon the unelectrified plate of resin, and after having remained some time in this situation, the resinous disc will have suffered the decomposition of some of its superficial electricity. The resinous portion will have combined to neutralize, as far as it may be able, the free vitreous electricity of the metal; and upon the removal of the upper disc, the resinous plate retains a charge of vitreous electricity. Thus we obtain an electrophorus, the effects of which are directly contrary to those of the original one, which has so long occupied our attention.

Com
tion
plate

(105.) The best composition for the resinous plate is found to consist of equal weights of shell-lac, resin, and Venice turpentine, melted together. These ingredients are to be poured, while in a fluid state, into the tin case prepared for their reception; or if no permanent case be required the mixture may be poured into a tin rim half an inch deep, placed upon a smooth marble slab, from which the cake may easily be separated when cold.

Mr. Cavallo states that an electrophorus, which he had made of the second sort of sealing-wax, spread upon a thick plate of glass, six inches in diameter, when once excited would charge a coated phial several times successively so strongly as to pierce a hole through a card with the discharge. "Sometimes the metal plate, when separated from it, was so strongly electrified that it darted strong flashes to the table upon which the electric plate was laid, and even into the air, besides causing the sensation of the spider's web upon the face when brought near to it, like an electric strongly excited." Cavallo's *Electricity*, vol. ii. p. 53.

On the subject of the Electrophorus, consult Volta, *Jour. de Phys.* vol. viii.; Henley, *Phil. Trans.* lxvi. p. 513; Achard, *Mém. Acad. Berol.* 1776, p. 122; Cavallo, *Phil. Trans.* 1777, p. 116, 388; Ingenhouz, *Phil. Trans.* vol. lxviii. p. 1027; Henley, *Phil. Trans.* vol. lxviii. p. 1049; Robert, *Jour. de Phys.* vol. xxxviii. p. 183; Biot, *Physique*, vol. ii. p. 374.

§ II. *The condenser, and its application.*

(106.) From the laws of electrical distribution which have been already investigated, it appears that one conductor, charged with a given quantity of electricity, will communicate by contact to another unelectrified and insulated conductor, a certain quantity of the same free electricity with which the former conductor is endowed. Throughout the case now enunciated, the two conductors are supposed to be placed in free space, or at least to have all other bodies situate beyond the sphere of influence of the fluid distributed to them.

Let us now proceed to show that the quantity of electricity communicated to the second conductor may vary greatly if the last condition specified be not strictly complied with. In fig. 64, A is a metal disc, having a strong wire and knob affixed to its upper surface. By bending the wire, a loop is formed through which there passes a glass rod B, which serves as an insulating handle. If now the knob be allowed to touch the excited prime conductor of a machine, the wire and plate A will receive a certain charge of electricity, which may be roughly measured by touching the ball of the electrometer, fig. 32, with the plate A. That this experiment may succeed well, it is necessary that the charge of the prime conductor should be but slight, and consequently the divergence of the gold leaves will not be considerable. Now we may conclude that as the conductor is of considerable magnitude when compared with the plate A, the quantity of electricity carried off by one contact is not great; and that therefore by another similar contact of the plate A, we shall be able to obtain a nearly equal quantity of free electricity. Let this contact however be made with some variation of circumstance; for at the same time that the knob touches the prime conductor let another metal disc C, having also a metal stand, which is to be held in the hand, be brought near to A; so that the planes of the two plates may be parallel to each other, but not so near that any spark may pass from one to the other. While they are in this relative position, let this system of bodies be withdrawn from the prime conductor, and then also remove the plate C, and apply the plate A to the electrometer as before. It will then be found that the leaves diverge much more widely than before, and consequently the plate A has carried off a quantity of electricity much greater than during the former contact.

By a recurrence to the principles of induced electricity we shall obtain a ready explanation of these effects. The body A receives in the first case its ordinary charge of communicated electricity, but in the second case, upon the approach of the plate C, the natural electricity of C is decomposed by the influence of the electricity, (be it of what kind it may,) that is disposed upon the plate A. Of the two electricities developed in C by this decomposition, the one that is of the same kind with that upon A is repelled to the earth, and the opposite kind is attracted towards the upper surface of the plate C. In this position it is able to attract to the under surface of the plate A a further quantity of the free electricity of the conductor, and this upon its arrival will produce a further decomposition upon the disc C. Thus will these effects take place in fact simultaneously, (although, for the sake of illustration, they have been traced in a consecutive order,) until an equilibrium is established between the quantity of free electricity which the conductor can afford to A, and the quantity of the opposite electricity which the attractive force of this electricity can draw to the disc C from the great reservoir the earth.

As long as the plates A and C are near to each other, a great portion of these electricities are rendered latent by their mutual influence, but upon the separation of A and C beyond their sphere of influence, both the electricities again resume their free state; the redundant fluid of C returns to the earth, and the redundant fluid of A having no channel by which it may escape, is capable of affecting the electrometer to a degree much greater than if the disc C had not been employed in the experiment.

(107.) We shall now be enabled to proceed to a description of the *Condenser*; an instrument frequently employed for the purpose of obtaining a considerable quantity of electricity from a feebly excited substance, in order that this electricity may be transferred to the electroscope for further examination. Condenser.

In fig. 65, B is a metal disc, supported by a stand of the same nature. A is a similar disc fitting upon the upper surface of B, and having an insulating handle proceeding from its centre, and also a small metal pin and knob affixed to its circumference. The under surface of the plate A, and the upper surface of the plate B, are coated respectively with a film of of any non-conducting resinous varnish. If now we wish to condense the charge of electricity which may be obtained from some feebly excited body, the metal pin from the plate A is placed in contact with the body, at the same time that by retaining the stand B in one hand it is allowed to communicate freely with the earth. It is obvious that by this process the charge which the plate A is capable of receiving is considerably increased, the electricity is condensed, and in a great measure rendered latent, so long as A and B retain their relative positions. Next, let the contact between the pin and the excited body be destroyed, and then, by means of the insulating handle, raise the disc A from the stand, and apply the pin to the cap of a delicate electrometer; a great portion of the electricity of A, which the presence of B had rendered latent, will be set free, and the electrometer will be sensibly affected. The object of the varnish upon the surfaces of the plates is to prevent the immediate communication of electricity by contact; and it is plain, from theory, that the thinner this interrupting stratum can be made the better. A plate of glass might serve to separate the two discs, but is exceedingly liable to the condensation of moisture upon its surfaces, by which the insulating property is greatly impaired; and it is also found, that when a disc of glass is employed as the interposed plate, a very considerable portion of the induced fluid remains affixed to the upper surface of the glass, after the insulated metal plate has been removed, by which the effect upon the electroscope is sensibly deteriorated.

Such is the condenser of Volta, with whose name the instrument is usually associated, although Æpinus had before constructed a similar apparatus. There are also many other instruments in which the same principle is employed under various modifications, according to the peculiar views or purposes of the inventors, who have given to them the names of condensers, doublers, or multipliers. From these we shall select such as appear most worthy of description, from their real utility to the practical electrician; and as it is obvious that the principal use of the condenser is to render sensible the presence of minute quantities of electricity, we shall be prepared to find it an important addition to our electroscopic apparatus.

Cuthbertson's condenser.

(108.) Cuthbertson's condenser consists of two circular brass plates, fig. 66. The one A, which is called the receiving plate, is supported by a glass pillar, while the other B, which is called the condensing plate, rests upon a pillar of brass, or some conductor, jointed at the bottom so that it may fall back into the position represented by the dotted lines of the figure. If the plate A be made to communicate by the hook at the back of its ball with any feebly excited body, the presence of the plate B which communicates with the earth will condense upon A a greater quantity of electricity than it could otherwise receive. Let the communication between the plate A and the electrified body be destroyed, and then withdraw the plate B. By this process the electricity upon A will remain no longer latent, and may be communicated by contact to the cap of an electroscope for examination.

Condensing electroscope.

(109.) By the combination of this apparatus with Bennet's gold-leaf electroscope, we arrive at the most convenient and delicate instrument of this species. In fig. 67, A is the receiving plate affixed to the cap of the electroscope, and communicating with the ground by means of its conducting pillar C, and capable of being withdrawn by turning upon its movable joint. The practical application of this instrument is sufficiently obvious from the explanations already given.

Condensing electroscope of Volta.

(110.) Fig. 68 represents an instrument precisely similar in principle, but differing slightly in its construction. This instrument, the condensing electrometer of Volta, has justly some claim to attention, from having been employed by that celebrated experimentalist in examining the weak electricities of the galvanic pile. It is in fact the discs of the condenser, in combination with the straw electrometer, which we have already sufficiently described.

Ch

Cava multi

(111.) *Cavallo's multiplier.*—This ingenious instrument is represented by fig. 69. It consists principally of four circular brass discs, A B C and D. A is supported by an insulating glass stem H, firmly fixed into the wooden base of the instrument Q R S; B is a similar disc, having its insulating support I affixed to a lever L K, moving upon a pivot at K. C is a similar disc, which like A is supported by an insulating rod G, fixed into the board Q R. The fourth disc D, is not insulated, being supported by a metal rod. When the lever K L is placed as the plate represents, the plane of the disc B is parallel to the plane of the disc A, and distant $\frac{1}{70}$th of an inch. The plane of the disc D is also parallel to the plane of the disc C, and capable of any variation of distance by means of the slider F P, into which its supporting rod is affixed. O *m* is a small wire fixed to the plate B, which when B is as near as possible to A, touches a strong vertical wire N, for the purpose of forming a communication with the earth.

Let us now suppose the plate A to be connected with any very feebly electrified body, and for the sake of illustration let the electricity developed be vitreous. The lever being placed in the position represented by the plate, the disc B is in communication with the earth, and will therefore have attracted towards it a portion of resinous electricity, by which means also it will enable A to receive a greater portion of the vitreous electricity of the excited body. Upon removing the lever for the purpose of bringing it to the position represented by the dotted lines, O *m* ceases to touch the wire N, and the plate B becomes insulated. The resinous electricity which had been latent during its proximity to the vitreous electricity of the disc A is set free, and finally by the small wire O *m* coming in contact with the plate C, the free electricity of B is shared between the two discs B and C; but in consequence of the presence of the plate D, which communicates with the earth, C is enabled to receive a much greater portion of fluid than is left upon the movable disc B. By successive motions of the lever, any number of repetitions of these effects may be produced, until a very considerable charge of resinous electricity has accumulated and become latent upon the disc C. By withdrawing the slider F P, the plate D is removed from the presence of the disc C, and as there is no longer any power capable of rendering latent the resinous electricity upon C, it will be found to have acquired a charge capable of affecting the electroscope. It is obvious that there is a limit beyond which the multiplication of electricity by this instrument cannot take place; because after a certain time the electricity upon C will have accumulated to such an extent, that upon withdrawing the disc B from contact with C, it will carry back as much electricity as the charge upon the disc A can enable B to retain when in a state of communication with the earth.

Nicho spinn conde

(112.) *Nicholson's spinning condenser.*—Fig. 70 and 71 are designed to convey some idea of this singular instrument. Fig. 70 represents in outline a

ical
icity.

vertical section. "A is a metallic vase having a long steel axis which passes through a hole in the stand H at K, and rests on its pointed end in an adjustable socket at C. The use of the vase is by its weight to preserve for a considerable time the motion of spinning, which is given by the finger and thumb, applied at the top of the instrument. The dark parts D and E represent two circular plates of glass, nearly one inch and a half in diameter. The upper plate is fixed to the vase, and revolves with it; the lower is fixed to the stand. In the lower plate are inserted two metallic hooks F and G, diametrically opposite to each other. They are cemented into holes drilled into the edge of the glass which is nearly $\frac{2}{10}$ths of an inch thick. In the upper plate are inserted in the same manner two small tongues of the fine flatted wire used in making silver lace. These tongues are bent down so as to strike the hooks at each revolution; but in all other positions they remain freely in the air without touching any part of the apparatus. At C is a screw, which by raising or lowering the vase, keeps the faces of the glass planes at any required distance from each other. The contiguous faces of the glass planes are coated with segments of tin-foil, as represented in fig. 71. Each of the tongues from the upper disc communicates with one segment of tin-foil upon the same disc; the hook F also communicates with that coating of the lower plate which is the nearest to it, but the hook G is entirely insulated from the whole apparatus, and is intended to communicate only with the electrified body, or an atmospheric conductor. The lower coating nearest to G is made to communicate permanently with the stand H, and consequently with the earth.

"In this situation suppose the motion of spinning to be given to the apparatus, one of the tongues will strike the hook G, by which means the upper coating annexed to that tongue will assume the electric state of the body with which G communicates; and the electric charge thus received will be the greater in consequence of the proximity of the lower uninsulated plate, to which at that instant it is directly opposite. The tongue G with its plate or coating proceeds onward, and after half a revolution, arrives at the situation to touch the hook F. The upper coating with its tongue, the lower coating on the side of F, and the hook F itself must then constitute one jointly insulated metallic mass, throughout which the charge of free electricity received at G is dispersed. Of this electricity the greater part will be determined towards the hook F," (according to the principles laid down in our third chapter.) "The motion being continued, the coating and its tongue instantly pass on, leaving F electrified, and proceed to bring another charge from G, which is to be deposited at F, as before. The electroscopic balls at F will therefore very speedily be made to diverge." (Nicholson's *Journal*, April, 1797.)

(113.) The following general observations, by the late Professor Robinson, on the various methods for ascertaining minute degrees of electricity are so excellect that we feel no hesitation in presenting them to our readers.

1. "If the absolute quantity of electricity be small, and pretty much condensed, as that produced by a small tourmaline when heated, or by a hair when rubbed, the only effectual method of manifesting its presence, and ascertaining its quality, is to communicate it to a very delicate electrometer; i. e. one that is very light, and has no great extent of conducting surface." The electroscopes of Haüy or of Coulomb are best adapted to this purpose.

Chap. V.

2. "When we wish to ascertain the presence of a considerable quantity of electricity which is dispersed or expanded into a great space, and is little condensed, such as the constant electricity of the atmosphere in clear weather, or such as the electricity which remains in a large Leyden jar after the first or second discharge, this may be best ascertained by means of Cavallo's collector, or multiplier, or by the condenser.

3. "When the electricity to be ascertained is neither very considerable in quantity, nor much condensed, such as the electricity of the hair of certain animals, of the surface of chocolate when cooling, &c. In this case, the best method is to apply a metallic plate furnished with an insulating handle, such as one of the plates of the doubler, to the electrified body, and to touch the plate with a finger while it remains sometime in this situation, which done, the plate is to be removed, and brought near to a sensible electroscope; or its electricity may be communicated to the plate of a small condenser, by which it will be rendered more apparent. In this operation, care must be taken not to bring the plate too near the body whose electricity is to be examined, lest the friction likely to happen between the plate and the body should produce some electricity, the origin of which might be attributed to some other causes."

(114.) It may be thought by some that we have described but few of those ingenious instruments which have been constructed for the purpose of rendering sensible minute degrees of electrical excitation, but in fact the extreme delicacy of Coulomb's electroscope precludes all necessity for the more complicated apparatus of spinners, doublers, multipliers, &c. These instruments may however be sometimes required for certain peculiar purposes of investigation, and therefore we subjoin the necessary references for all the most important instruments of this description.

Cavallo's Condenser, *Jour. de Phys.* 1789, p. 258; Hemmer's Condenser, Gren's *Jour. de Phys.* vol. ii. part ii. p. 210; Dumotier's Condenser, *Jour. de Phys.* vol. xxxi. p. 431; Weber's Condenser, Gilbert's *Annalen*, xi. p. 344; Wilson's Condenser, Doubler, and Multiplier; Nicholson's *Jour.* vol. ix. p. 19; Bennet's Doubler, *Phil. Trans.* 1787, p. 288; Nicholson's revolving Doubler, *Phil. Trans.* 1788, p. 403; Cavallo's improvement upon Bennet's Doubler, *Phil. Trans.* 1788, p. 1; Hachette and Desorme's Doubler, *Bulletin de Soc. Philomathique*, No. 83; Cavallo's Multiplier, vol. iii. of his *Treatise upon Electricity*, p. 98.

§ III. *The electrical jar, and battery.*

(115.) In our historical sketch we have adverted to the discovery of the Leyden jar for the accumulation of electricity, either by Kleist or Muschenbroeck; and in the present section we propose to describe this important instrument, both in its simplest forms, and in the more complex construction of the electrical battery.

Electrical jar.

Fig. 72 is a plain glass jar; the shaded part represents a coating of tin-foil, affixed by paste or gum water, to the outside of the jar; while within, there is another similar coating of tin-foil, of the same extent. A metal rod, terminated by a ball, is made to touch the interior coating of the jar, and reaches two or three inches above the top. As may be observed, upon inspection of the figure, neither the exterior nor interior coating, is allowed to extend very near to the edge of the jar.

(116.) Let the jar, thus prepared, be placed upon a plate of glass, or some insulating support, with its ball nearly in contact with the prime conductor of an electrical machine. Upon setting the machine in motion, a feeble spark will pass from the conductor to the ball; and on removing the jar with one hand, at the same time touching the ball with the other hand, scarcely any effect will be perceived. The jar, in short, will be found to have received no charge of electricity. If now, instead of placing the jar so that the exterior coating remains insulated, we touch the outside of the jar with the hand or any conducting body, or affix a chain communicating freely with the earth; upon again putting the machine in motion, an abundant succession of sparks will pass from the conductor to the ball. Remove the jar, holding it by its exterior coating in one hand, and then touch the knob with the other hand, or with any conducting substance; a strong spark will be perceived, and a sort of convulsive shock will be experienced in the joints or muscles, which, to most persons, is extremely disagreeable. It is easy to perceive when the jar has received its full charge by the feebleness, or entire cessation of the sparks, passing from the conductor to the knob of the jar. If it be required to communicate the shock to more than one person, let all the party form a chain by joining hands, and let the person at one extremity of this chain touch the outside of the jar, while the person at the other extremity, completes the circuit by touching the brass knob. All will feel the shock, and the intensity of effect produced upon each will not be much less than it would have been, if he alone had completed the circuit between the two surfaces of the jar.

Franklin's experiments.

(117.) Having thus described the construction of the Leyden jar, it may be advisable, before we proceed to examine the rationale of its action, to refer to certain experiments which will point out the precise circumstances upon which its effects seem to depend. For these researches we are indebted to the labours of Dr. Franklin. His first efforts were directed to the ascertaining the relative states of the exterior and interior coating of the jar. By suspending an electrified pith ball from a silken thread, he found that it would invariably be attracted by the one coating, and repelled by the other. Hence it was evident that the two coatings were oppositely electrified. When the interior communicated with the prime conductor of a machine, it received a charge of vitreous electricity, and the exterior coating became equally charged with the resinous electricity. By reversing the communication, connecting the outside of the jar with the conductor, and the inside with the earth, the converse effects were produced, and the jar became charged to a degree of intensity as great as before.

(118.) Having arranged two jars, so as that the knob of each should receive electricity from the prime conductor, it is plain that both the jars would become similarly charged with vitreous electricity. On suspending an insulated pith ball near to the two knobs, it would be attracted by either until it had received a charge of free electricity, by contact, and then was repelled by both the knobs equally. But if of the two jars, the one were charged by its knob, that is, with vitreous electricity on the inside, and the other were charged by having its exterior coating in contact with the conductor, so that the interior would be resinously electrified; the pith ball being then suspended between the two knobs vibrated backward and forward from one knob to the other until both the jars were discharged.

(119.) Again, if the interior coating were made to communicate with the conductor, and the exterior with the rubber of the electrical machine, but at the same time having no communication with the earth, by any conducting body, the jar became fully charged as before.

(120.) It has already been remarked, that no charge could be communicated to the jar, unless the exterior coating communicated with the earth; and this, together with the last experiment, points out some important change to be performed upon the exterior of the jar, while the interior is receiving its charge. The oscillation of the small pith ball between the knobs of the two oppositely charged equal jars, having produced their mutual discharge, suggested, that in charging or discharging a jar, one coating gained as much electricity of the one kind, as the other did of the opposite kind. The process of withdrawing the electricity from a charged jar, was thus analyzed by Franklin. Having placed the jar upon an insulating stand, he suspended a linen conducting thread near to the exterior coating. By repeatedly touching the knob, which communicated with the interior, he was enabled, gradually, to discharge the jar; and in so doing, he found that, at every successive contact, a portion of the electricity on the outside became free, and the linen thread sprang to the exterior coating, in order that it might receive and remove the superfluous fluid.

(121.) The converse of this proposition applying to the case of a coated jar or disc receiving electricity, was thus elegantly investigated by Professor Richman. Two discs of tin-foil were applied as coating to the opposite sides of a plate of glass, so as to leave a clear interval between the tin-foil and the edge of the pane. The glass was then placed in a vertical position, and to each of the upper and opposite edges a thread was affixed, so that the two might hang parallel to each other on opposite sides of the glass. By communicating a charge of electricity to one of these coatings, the adjoining thread was repelled, and raised itself so as to form a certain angle with the surface of the glass, and at the same time an equal angle was formed by the other thread next to the tin-foil on the opposite side of the pane.

Fig. 73 represents a section of this apparatus, in which the strong dark lines mark the coated part of the plane. If any conducting body were brought near to one side of the plate, the thread on that side would sink, and form a less angle with the coated surface; but the thread on the opposite side would receive an additional elevation, equal in quantity to that which the former had lost. If one side were touched by the finger, the thread on that side would immediately and entirely collapse; but the angle of elevation of the other thread would be doubled. Hence it is evident that the angle intercepted between the two threads, is a constant quantity, dependant upon the charge, communicated to the plate in the first instance.

(122.) To return again to the researches of Franklin, we find him endeavouring to ascertain in what the efficacy of the coating, applied to a jar, consisted. What function does it perform? Does the accumulated electricity reside in the coatings, or upon the glass?

By charging a jar and placing it upon an insulating stand, he found, that after the lid of the jar and the knobbed wire were removed, the charge still remained, and that by connecting the interior and exterior coatings, the jar was discharged as usual. In the next place, having charged a jar, of which the inner coating consisted solely of a quantity of water, he poured out the water into a clean jar, and as he could obtain no shock from the water thus removed, he concluded that he had not abstracted the electricity from the interior of the jar. He then filled the first jar again with fresh water, and proved that the electricity had remained all the time in the jar, by obtaining from it a shock as usual. Thus was he led to the true explanation of this phenomenon, which may also be readily obtained by any one from the following experiment.

(123.) *Exp.* Let a large tumbler glass, fig. 74, of a conical form, have an exterior and interior coating of tin-foil, fitted nicely, but not cemented to the surfaces. Charge this jar as usual, place it upon a glass plate for insulation, and holding it by the uncovered part, lift out the inner coating of tin-foil, and then raise the glass from its outer coating also. By touching the outside and inside of the glass simultaneously, no perceptible shock will be obtained, neither is there any effect produced by touching either, or both the coatings; but let these coatings be again carefully adjusted to their places, on the opposite sides of the glass, and a shock may be obtained in the ordinary manner. Hence it is evident, that in the Leyden jar the electricity is accumulated upon the glass, and not in the coating substances, and that the latter are only necessary for the formation of a complete communication between every point on the exterior with every point on the interior, at the instant of the discharge.

(124.) A very slight degree of consideration will show, that in fact the coated jars and coated discs are but peculiar forms of the condenser, which we have already so fully described. In this instrument there are two metallic surfaces, separated by a non-conducting body, and these may be removed to variable distances from each other, in which respect alone the instrument differs from a coated jar, which consists also of two metallic surfaces, with an interposed non-conductor. If similarly employed, the effects also of the apparatus are the same; for if we communicate a considerable charge of electricity to the upper plate of a large condenser, while the lower disc has a free communication with the earth; and then having touched the lower plate with the fingers, and apply the thumb to the upper disc, a complete discharge will be produced, and a shock will be obtained similar to that from a jar having a coated surface of equal extent.

Perhaps it would be difficult to adduce a more striking proof of the similarity or identity of the two cases, than that which is afforded by the discharge of a jar, or a condenser by alternate sparks from the two coated surfaces.

(125.) *Exp.* Let a charged jar be placed upon an insulating stand, and a condenser also be fully charged, by allowing the lower disc to communicate freely with the earth, and after the charge has been obtained, let this communication be destroyed, so that the lower plate becomes insulated like the outer coating of the jar. The inner coating of the jar and the upper disc of the condenser, are then similarly electrified; as also the outer coating of the jar and the lower disc of the condenser. Upon presenting a finger to the outer coating of the jar, or to the lower of the two discs, no effect will be produced; because all their electricity is rendered latent by the presence of that resident upon the opposite coated surfaces. Next, let the finger be presented to the ball communicating with the inner coating, and to the upper disc of the condenser. In both these cases a small spark will be obtained, but a considerable portion of the electric charge will remain, being rendered latent by the electricity of the opposed surfaces. Again, approach the outer coating, and the lower disc, and from each a feeble spark may now be obtained. By these alternate contacts, the two oppositely charged surfaces, both of the jar and the discs, may be entirely discharged; because at each repetition of the process a portion of electricity is set free by the removal of the small excess on the side of the surface touched.

(126.) Hence it is very evident that the complete explanation of the effects produced by the Leyden jar, is to be deduced from the principles of electrical induction; because it is the power of accumulating the opposite electricity upon the exterior of the jar which allows of the successive accumulation of that on the inside, by their two opposite powers of rendering each other latent as they arrive at the positions occupied by each respectively.

Let us, however, proceed to a more minute analysis of these effects, by which the action of the Leyden jar will, it is hoped, receive a very satisfactory explanation.

Place an uncharged jar upon an insulating stand, (fig. 75,) and let its exterior surface communicate with the pith-ball electroscope already so frequently referred to. Impart two or three sparks to the brass ball of the jar, and immediately the pith balls will diverge with vitreous electricity. The exterior coating of the jar has, therefore, suffered the decomposition of its natural electricity.

While things are in this state, touch the electroscope, and the wires will again fall into their natural vertical position. By this contact the escape of the vitreous electricity, which caused their divergence, has been facilitated; and it has become impossible to remove from the interior surface all the vitreous electricity which has been communicated to it. A part has become latent, and this can only have been effected by the influence of a resinous electricity. In fact, if we now touch the ball for the purpose of removing the portion of vitreous electricity which remains free, the electroscope, communicating with the exterior surface, will again diverge, but with resinous electricity.

The same arrangement of our apparatus being retained, we charge the prime conductor of a machine with a certain quantity of electricity, and then form a communication with the ball of the insulated jar. After the free electricity has become distributed between the conductor and the interior of the jar, the electroscope, communicating with the exterior, will diverge as before with vitreous electricity. If by touching the electroscope, we allow this electricity to escape, the repulsive force which it exerted upon that on the interior of the bottle, ceases to exist, and the ball again placed in communication with the conductor of the machine, will show itself capable of receiving an additional charge of electricity. The electroscope will then again begin to diverge, and always with vitreous electricity. If a passage be offered for the escape of this electricity, the ball becomes again capable of receiving a further quantity of electricity from the conductor. The electroscope again diverges, and so on in succession. This phenomenon is repeated continually, in the same manner, until the portion of vitreous electricity, which remains in a state of freedom upon the interior surface, shall have arrived at such a degree of accumulation, as to hinder, by its repulsive force, the introduction of any additional quantity of electricity of the same nature, arriving from the surface of the conductor. The jar has then become fully charged, and its discharge may be effected by any of the ordinary processes for that purpose.

(127.) A very cursory inspection of these principles, will prove to us that a given quantity of electricity to be abstracted from the prime conductor of a machine, may be employed for the charging of two or more jars, almost as powerfully as if the whole were communicated to one only. For this purpose, let the jars be placed consecutively as represented in fig. 76. A chain or wire serves to convey the electricity from the prime conductor to the ball of the first jar. The ball of the second jar is similarly connected with the coating of the first, and another chain forms a communication between the coating of the second jar and the earth.

Upon the afflux of electricity to the ball and interior coating of the first jar, the natural electricity of the exterior coating undergoes decomposition; the resinous part is rendered latent by the influence of the vitreous electricity within the jar, and the vitreous part is repelled to the interior of the second jar, where it performs the same office as the similar electricity did when primarily communicated to the first jar. The vitreous fluid developed at the exterior of the second jar is repelled to the earth, and any required portion of resinous fluid is conveyed to the exterior coating of the same jar, in order by its influence to render latent the vitreous electricity which arrives at the interior of the jar. Let all the connections now be interrupted, and the two jars will have received their full charge, and it is evident that whatever upon these principles of explanation can be proved true of two jars, may be extended to any number of jars arranged consecutively, and properly connected for the purpose.

(128.) Hitherto we have spoken of the Leyden jar in its most simple form, but it may be desirable now to describe the best construction at present known for this important instrument of electrical research. A B, fig. 77 is a glass jar, having a mouth sufficiently wide for the convenient application of the tin-foil to the interior surface. C is a hollow brass cap, cemented into a glass tube, which reaches to the bottom of the jar, and is fastened into the wooden disc that closes its mouth. This wooden disc or plate should be well dried by baking, varnished on both sides, and cemented into the jar. D is the knob of a small brass wire, which forms the communication between the cap C and the inner coating of the jar. This wire, passing loosely through a small hole in the cap C, may be removed at pleasure, for the purpose of cutting off all communication between the cap and the interior coating. In consequence of this wire not reaching quite to the bottom of the jar, the lower part of the tube is provided with a coating of tin-foil, which joins to the inner coating of the vessel. Enough has already been said of the layer of tin-foil which is to be pasted on the outside, to correspond with the foil within; and neither ought to extend too near to the top of the jar. It is also an improvement to spread a delicate film of some resinous varnish, both on the inside and on the outside, over those parts of the glass which are not occupied by the foil. At the bottom of the jar there is a hook affixed, to which a chain may be conveniently suspended, for the purpose of communication with the earth, or any appropriate conductor.

It is obvious, that when a jar of this construction has received its charge of electricity, the wire may be carefully withdrawn, or suffered to fall out by reversing the jar; and that then no discharge can possibly take place until the wire be restored; neither is there any loss of electricity, even if the jar be carried in the pocket.

Thicl of gl

(129.) In the construction of the Leyden jar, the thickness of the glass is an important consideration; for as it has been proved that the power of accumulation, by which the charge is obtained, depends upon the mutual attraction of the molecules of two fluids, according to a force varying with the inverse square of the distance; it is evident that the intensity of charge which may be communicated to any coated non-conductor of given superficial extent, will increase rapidly as the thickness of the non-conducting body decreases; and hence the thinner the glass, the greater will be the charge. Such, at least, will be the case, provided this law undergoes no modification in consequence of the attractive and repulsive forces being exerted through a non-conducting body, instead of through the air or free space. On this subject there is little of conclusive experiment to guide our determinations: some researches of Mr. Cavendish led him to conclude that the charges which might be imparted to jars of given superficial extent, varied inversely as the thickness of the glass.

In practice, however, it is found impossible to diminish the substance of the non-conducting body interposed between two oppositely charged surfaces, beyond a certain extent. Thus, at some degree of intensity, a spark will force a passage through the plate of air between the two discs of the condenser. At some point of accumulation upon the opposite surfaces of a charged jar, although the electricities, being latent, have no action upon other bodies, yet they tend towards each other with such violence as to force a passage through the substance of the glass. To obviate this danger, a sufficient thickness must be allowed for the jars employed in experiments of this nature, and it is found that the common glass jars, to be purchased at the glass-houses, are as thin as can with safety be made use of. Mr. Brooke has suggested, that a layer of paper should be placed between the glass and the tin-foil; and he states, from his own experiments, that jars, so constructed, were able to contain electrical charges of great intensity, much better than those which had not been so prepared.

Owing to the more uniform thickness of glass balloons, the late Professor Robinson preferred them for the construction of electrical jars. A coated flask of this kind is represented by fig. 78.

A very excellent jar is mentioned by some authors as having been constructed by the same able electrician, in the following manner: A long-necked phial was made of sheet-tin, and then coated intirely on the outside with sealing-wax $\frac{3}{10}$ths of an inch thick. The sealing-wax was then coated with tin-foil, all but the neck; the tin plate corresponded with the inner coating and wire, and the tin-foil with the outer coating, while the wax acted the part of the glass in a common jar.

(130.) An ingenious little instrument, called Cavallo's self-charging jar, is thus constructed. Take a glass tube eighteen inches long, and an inch and an half in diameter. Coat one-half with tin-foil on the inside, and close the orifice of the coated end with a cork through which a wire passes, touching the inner coating, and terminating in a ball on the outside. By holding the uncoated part in one hand, and rubbing the outside of the coated part with the other hand, touching at intervals the knob with the rubbing hand, the inside coating gradually receives a charge. If now the outside of the coated part be held in one hand, and the ball be touched with the other hand, a shock will be obtained.

(131.) It will now be evident to our readers, that a plate of glass, or any non-conductor may be coated in a manner similar to the jar, and that its effects will be the same. Dr. Bevis appears first to have proposed this change, and Dr. Franklin made considerable use of coated plates in his experiments; but at present the jar is the form under which the instrument is almost universally employed. Beccaria constructed a plate consisting of a resinous mixture, containing equal quantities of pure colophony and pulverized marble. By spreading this to about the thickness of one-tenth of an inch with a hot iron; and then coating the surfaces with tin-foil, he considered that he had obtained an instrument capable of a greater charge than a glass plate of equal extent; with the advantage of being much less endangered by the effects of a spontaneous discharge.

A plate of mica has also been employed for the formation of a coated pane, as its strength enables it to resist an electrical charge of considerable intensity.

The electrical battery.

(132.) Gralath, who published a work on electricity in 1747, first proposed to combine together the effects of several jars, so as to construct what is now very appropriately termed an electrical battery. Fig. 79 is a representation of this piece of apparatus, in which every essential part is so clearly expressed by the plate, as to require scarcely any specific description. The interior of the wooden box, in which the jars are arranged, or at least the bottom upon which they are placed, is coated with tin-foil, for the purpose of ensuring a direct communication between all their exterior surfaces; and from this conducting substance, a chain or wire communicates with a ring seen at the front of the case, by which, in charging the battery, a connection is formed with the earth, and which, of course, must be also employed for completing the circuit, between the exterior and interior coating, in order to effect a discharge.

The rods which are seen passing through the balls at the top of each jar, are of brass, and serve to connect all the interior surfaces together; but it is convenient to have all the transverse rods passing in one direction, only laid loosely across the rods passing in the other direction; by which means we are enabled to charge only one or more of the rows of jars, as may best suit our experiments. This is explained by fig. 80, which represents a horizontal view of twelve balls, with three fixed longitudinal rods, and two shorter transverse ones laid across, so as only to employ eight of the twelve jars contained in this battery.

In charging an electrical battery, we have only, as in the case of a jar, to form a connection between the rods which communicate with the interior surfaces, and the prime conductor of a machine in action; at the same time allowing the exterior surfaces to communicate with the earth, by means of the ring before mentioned; and it may, in general terms, be asserted that the quantity of electricity, of given intensity, contained by different batteries, varies directly as the extent of coated surface. The degree of intensity to which any given extent of coated surface may be charged by the successive accumulation of electricity, as we have before seen, will vary according to some inverse ratio of the thickness of the glass, of which the jars are made, and of course the thinner the glass the greater would be the charge of which the battery is capable; but in practice, it is found that the jars cannot, with safety, be made thinner than they are usually obtained at the glass-house for other purposes.

(133.) If it be required to charge a large battery from the action of a small machine, we may resort to an artifice founded upon the experiment described in art. 127. In fig. 81, four jars are arranged, without the frame or case, for greater clearness in illustration; and it is essential that each jar or section of the battery to be charged by this method, should occupy a separate insulating stand. A, B, C, D, are the balls communicating with the interior surfaces. A wire is passed from the coating of the first jar to the knob of the second; another wire from the coating of the second to the ball of the third, and so on; while the exterior coating of the last jar is allowed to communicate freely with the earth. Suppose vitreous electricity be conveyed from the prime conductor of the machine to the first ball A, the whole of the resinous electricity that can be furnished by decomposition from the exterior coating of the jar A, is put in requisition to render latent the vitreous electricity at the interior of the same jar; while the vitreous electricity resulting from this decomposition is repelled to the jar B, which thus becomes charged, and a similar series of effects is transferred in succession from one jar to another, so that all become charged. The interior surfaces of all the jars have accumulated vitreous, and the exterior surfaces resinous electricity. A moderate degree of caution in preserving the insulation, will enable us to derange all the former system of contacts, and to pass a wire through all the balls, and another to all the exterior coatings, so that at last we are in possession of a battery of four jars charged from the same quantity of electricity, which might have been employed in the charging of one jar alone.

Effect of humidity.

(134.) The increased effect, as to its capability of receiving a charge, which is produced in a jar by a slight degree of moisture upon the surface, was accidentally noticed by Mr. Brooke, and an analogous phenomenon was remarked by Mr. Cuthbertson in 1792. He found that a recently coated jar, which had not become perfectly dry, received a greater charge than could afterwards be communicated to it, when it had been deprived of all moisture. He then took a dry jar, and having breathed into it, he found that the power it had then acquired, when compared with that which it before possessed, bore the increased ratio of twelve to five. Resuming this subject in 1796, he found that on a dry day in March, a battery of fifteen jars, containing seventeen square feet of coated surface, would ignite eighteen inches of wire, but by breathing into each jar through a glass tube, the battery acquired a power of receiving a charge which would ignite sixty inches of the same wire. This is certainly a very singular circumstance, and one which it is important for the practical electrician to bear in mind.

Lateral explosion.

(135.) There is one phenomenon connected with the communication of an electrical charge to a jar or battery, which may fairly claim our attention in this part of our treatise.

It was, we believe, first remarked by Mr. Henley, that when a jar is discharged by means of a bent metallic wire, not having a glass insulating handle, some degree of shock is experienced by the hand which grasps the wire, especially if the quantity of electricity to be discharged be considerable. Also, if one end of a chain be placed in contact with the exterior coating of a charged jar, and the remaining part of the chain be loosely laid upon a table, it is found, that on the discharge of the jar, in a darkened room, the chain, though it forms no part of the circuit, becomes luminous by the passage of sparks from one link to another, and therefore has, in some manner or other, been affected by the discharge. The same effect may be produced when the chain is not quite in contact with the exterior coating of the jar, in which case a spark also passes from the jar to the chain whenever the general discharge takes place.

This phenomenon, which is known by the name of the *lateral explosion*, is, however, better illustrated by the following experiment of Dr. Priestley. "When a jar is charged, and stands upon the table as usual, insulate a thick metallic rod, and place it so that one of its ends may be contiguous to the outside coating of the jar, and within about half an inch of its other end, place a body of about six or seven feet in length, and a few inches in breadth; then put a chain upon the table, so that one of its ends may be about one inch and an half distant from the coating of the jar. To the other end of the chain apply one knob of the discharging rod, and bring the other knob to the wire of the jar, in order to make the explosion. On making the discharge in this manner, a strong spark will be seen between the insulated rod, which communicates with the coating of the jar, and the body near its extremity, which spark does not alter the state of that body in respect to electricity; hence it is imagined, that this lateral spark flies from the coating of the jar, and returns to it at the same instant, allowing no perceptible space of time, in which an electrometer can be affected. Whether this lateral explosion is received on flat and smooth surfaces, or upon sharp points, the spark is always equally long and vivid." Cavallo's *Electricity*, vol. i. p. 283.

Now in all these experiments, we think that we may again recognise the effects of electrical induction; and that from this principle we shall be able to deduce a more satisfactory explanation of the phenomenon, than that proposed by Mr. Cavallo. Let us consider the last mentioned as the most clear case, and, as it is evident, that the laws which are applicable to the one, may also be brought to bear upon all the other cases recorded, the insulated metallic rod being in contact with the exterior coating of the jar, will be affected by the charge which that coating receives. Suppose the jar to receive internally a charge of vitreous electricity, the exterior coating will become resinously electrified, and the rod will either partake of this resinous state throughout, or will become vitreously electrified at that extremity which is farthest from the jar and nearest to the long insulated body. In whichever way the rod becomes electrified, as it has no connection with the other body, and yet is very near to it, the effects of induction must take place. The natural electricity of the long insulated body will be decomposed, one of its elementary principles will be attracted towards the end which is presented to the rod, and there rendered latent, and therefore protected from dissipation. The opposite electricity will be repelled to the other end of the insulated body, and from the very form of the conductor upon which it resides, it is in the most favourable circumstances for being dispersed into the surrounding atmosphere. Let us now suppose, that after a short time the jar is discharged, its exterior coating, and the rod connected with it, will immediately return to their natural state; the electricity which had been collected, and rendered latent at the nearest extremity of the long conductor, will be again set at liberty, and in dispersing itself over the body upon which it resides, it again unites with the opposite electricity, which had been repelled to its most distant extremity. But some portion of this electricity has been dissipated, and therefore the two principles will not be found in their just quantity required for mutual saturation; that electricity which had been latent will be found in excess; and the conductor is, in fact, possessed of a charge of free electricity. The electrical charge will, upon the principles of arrangement already explained, assume a state of great comparative intensity at the two ends of the conductor, and as one of these ends is near to the rod which touches the exterior coating of the jar, which communicates with the earth, a spark must pass between the bodies to enable the conductor to return to its natural state.

All those circumstances, so minutely specified by Priestley as tending to the success of the experiment, seem to confirm our explanation of the phenomenon, that the conductor should be very long and very slender. The better, therefore, we say for the separation of the two electricities, and the dispersion of one of them, that the long conductor should not approach near to the exterior coating of the jar, but should be acted upon through the intervention of a sort of thin conductor projecting from the jar. Because, to us it appears that the form of this intermediate conductor, is most proper for affecting the longer one, and because the charge of electricity, immediately upon the outer coating of the jar, would not act so strongly upon the long conductor, from being rendered latent by the presence of the vitreous electricity within the jar. At the same time, the unelectrified state in which the long bar is found, after the passage of the spark which was quite inexplicable before, seems a necessary consequence, resulting from those principles upon which our explanation has been founded.

At the same time it may be just to state that, to the best of our recollection, the lateral explosion has been explained in a different manner, and supposed to depend upon the interruption of the circuit through which the discharge takes place. Thus, Mr. Cavallo states, " the cause of this phenomenon to be the interruption of the circuit made by introducing bad conductors into it; for as this interruption is greater or less, so the lateral explosion is more or less considerable." Even upon our view of the matter, this imperfect or interrupted circuit may not be without its effect; but we feel convinced that a few judicious experiments, made with a thorough understanding of the principles and peculiarities of induced electricity, would remove all the difficulty with which this phenomenon is at present encumbered.

Extent of charge.

(136.) In communicating an electrical charge to a jar or battery, we have shown that the two electricities, distributed at its opposite coated surfaces, are rendered latent by the effects of their mutual attraction, so that the jar may be highly charged, and yet, from having no free electricity, neither coating may produce any effect upon the gold-leaf electrometer, and hence the quadrant electrometer of Henley, depending upon the same principle, gives no just indication of the extent to which a battery is charged.

But although the two electricities thus circumstanced, have no effect upon other bodies, every molecule present upon each of the surfaces, exerts its due attractive force upon all the molecules of the other fluid upon the opposed surface; and also, its repulsive force upon all the molecules of its own mass of fluid of which it forms a part. Hence we may arrive at a knowledge of the limit, beyond which any given extent of surface cannot be charged. Suppose a current of electricity from the prime conductor of a machine, to be determined toward the interior coating of a jar; we know that its momentum will depend upon the form of the conductor, and the quantity communicated to it by the machine in a given time; and therefore, all other circumstances being favourable, we conclude that the fluid will continue to accumulate within the jar, and to become latent by the effect of the opposite electricity, which it will bring to the exterior coating, until the repulsive force of the molecules of electricity within the jar, is sufficiently great to counteract the momentum of the approaching current of electricity from the prime conductor; when, of course, no further accumulation can take place.

At this period the prime conductor will, by its points, if from no other part, dissipate electricity as fast as the machine can supply it. A jar then, during the process of charging, and as soon as the charge has arrived at its maximum, will have some portion of free electricity, shared between its interior coating and the prime conductor of the machine. The obstacles, therefore, to our obtaining a charge of indefinite magnitude upon a given extent of coated surface are these The imperfection of the air and glass, as barriers to the progress of electricity, and the limited decomposing, generating, or determining power of the machine. If glass were a perfect non-conductor, and had perfect strength to resist the passage of the mutually attractive fluids, however accumulated, we then must have a plate of thickness indefinitely small, in order that the two fluids might be precisely equal to each other in quantity and intensity. But it is found by experiment, that if the glass of a jar have not considerable thickness, the fluid forces a passage through, and the glass is fractured.

Again, if the air were a perfect non-conductor, (which perhaps in a pure state it really is,) and had at the same time a perfect power of resistance, so that electricity could not displace it, (which property it certainly has not,) there would be no necessity for such considerable spaces, as we are compelled to leave, between the extremities of the two coatings of a jar; and it is frequently found, that if we attempt to charge a jar or battery beyond a certain point, the electricities acquire a sufficient intensity of attractive force to burst their way through the air, and pass from one coating to the other, so that a spontaneous discharge takes place.

An electrical charge, which the air at some given density is capable of retaining in its place upon the two coated surfaces of a jar, will escape, if that density be sufficiently diminished. Of this mode of action we obtain an elegant illustration, by placing a charged jar under the receiver of an air pump, in a darkened room. As soon as a sufficient degree of exhaustion is produced by working the air pump, the fluid is seen to pass over the edge of the jar in a luminous torrent, from the vitreous to the resinous side; and thus, a mutual saturation again gradually takes place.

(137.) With any given battery, the point at which dissipation from the conductor becomes equal to reception from the cylinder or plate, will depend upon the activity or power of the machine, measured by the quantity of electricity which it furnishes in a given time. And if the producing power of the machine be given, we may consider the electrical charge of which any jar or battery is capable, to vary in the direct ratio of the superficial extent of the coated part, and in some inverse ratio of the thickness of the glass; yet in practice it is found impossible to judge of the intensity of the charge communicated to the jars or batteries, other than by the effects produced upon their discharge. For obtaining an estimate of this species, Mr. Cuthbertson proposed to measure the length of a wire of some given metal, and of given diameter, which the discharge of the battery is capable of igniting. This is, however, evidently a method not susceptible of great delicacy or accuracy. All those electrometers, described in chap. ii. which depend upon the repulsion of any two parts of the same system of bodies communicating freely, and charged with the same electricity, are inadequate to our purpose; because they measure only the repulsive energy of the free electricity, and render no account of that which has become latent.

(138.) Before we enter upon the task of describing those instruments which have been contrived for the purpose of measuring the charges of jars and batteries, we would wish to introduce to our readers, whom we are bound to consider as inexperienced electricians, an instrument of perpetual use for discharging jars without partaking of the shock, which would frequently be unpleasant, and even, in some cases, attended with danger. Fig. 82 represents this instrument, called a *jointed discharger*. A B is a handle of glass, B C, B D are brass wires terminated by brass balls at C and D. At B, is a joint which, allowing a freedom of motion to the two arms, enables the experimentalist to place the two balls at any convenient distance from each other. With this instrument it is easy to discharge a jar or battery, by bringing one ball in contact with the exterior, and the other in contact with some part of the interior system of arrangement; while the glass handle forms a protection from all the effects which take place in the restoration of electrical equilibrium.

Jointed discharger

(139.) The greater part of the instruments described in our second chapter for indicating and measuring free electricity, depended, primarily for their action, upon the repulsive forces exerted by molecules of the same electricity upon each other. It has, however, been proved, that the electric fluids which reside upon the opposite coated surfaces of a charged jar, have the power of mutually depriving each other of this repulsive property, which, in fact, accounts for their assuming what we have termed the latent state; and hence it follows, that neither the presence, nor the quantity of an electric charge, can be ascertained by any of the instruments already enumerated. But although the mutual repulsion between the molecules of the same fluid is in that case destroyed, or veiled, the attractive force between the respective molecules of the dissimilar fluids is unchanged, and appears to be in reality the probable cause of the temporary extinction of the self-expansive property.

That the repulsive power is thus destroyed, is easily proved by the fact, that if we touch either coating of the jar, the other coating remaining insulated, we are unable to remove the electricity which the former coating may be in contact with. That the attractive powers of the dissimilar fluids are not destroyed, is manifest from the fractures of the jars which sometimes take place by the spontaneous union of the two electricities, which thus force for themselves a passage through the substance of the glass.

There are, however, some other principles, which have been resorted to for obtaining measures of the electrical charge accumulated in a jar or battery.

Lane's discharging electrometer.

(140.) Of these we propose first to describe *Lane's discharging electrometer*. Fig. 83 is a representation of this useful instrument. A B is a strong bent glass rod, having at one end a brass cap and conical point C, by which it fits into the ball of a jar, or into a hole in the prime conductor of an electrical machine. At the other end of the glass rod is a ball D, perforated for the admission of a brass bar, having a ball at each end, and so constructed as to slide backwards and forwards through the ball D. If the instrument be fixed by its point C to a conductor, or to a jar, while the outer ball communicates with the other side of the jar, no discharge can take place, except between the body to which C is affixed, and the inner ball of the discharger. Hence, by sliding the bar along, the distance which the shock or spark has to traverse may be regulated. It is obvious that this instrument attempts to estimate the accumulated charge of a jar by measuring the distance in air which the discharge is capable of traversing. This will be subject to some variation from the changes to which the atmosphere is subject; and in the case of sparks at least, other changes may be produced by altering the form of the balls, or the conductor to which the instrument is affixed.

Henle univer discha

(141.) *Henley's universal discharger* is an instrument something similar in its principle, but is chiefly employed for the deflagration of metals by electrical discharges, and is extremely convenient in many galvanic experiments. As a measure it is little employed, except by placing different lengths of wire between its forceps, to be fused or ignited by the electrical discharge. A and B, fig. 84, are glass pillars cemented into a wooden stand. At the top of each of these pillars is a brass cap, so jointed as to move both vertically and horizontally. Through a spring tube at the top of this joint, the handle D or C passes, and is capable of being moved backwards or forwards by sliding it through the spring tube E. These handles are each composed of a strong brass wire, terminated by a ball, or point, or pair of forceps; and have at the other extremity a solid glass rod, to serve as an insulating handle. F is a small wooden table, having a slip of ivory glued longitudinally into its upper surface, and capable of being elevated or depressed by means of a screw G. In using this instrument, the two sides of the jar or battery are connected by chains or wires, with the two brass caps at the tops of the pillars. The substance through which the discharge is to be passed, is placed upon the stand F, or in any other way between the balls or forceps; and, by means of the insulating handles, the distance may be regulated so as best to suit the purpose of any required experiment.

Cuthl son's charg electr meter

(142.) Several different kinds of electrometer have been invented upon the principle of measuring the intensity of the electric charge, by the weight which the electrical forces might be able to overcome. The best of these, and we believe the only one now employed, is *Cuthbertson's discharging electrometer*. In fig. 85, A and B are glass insulating rods, supported by a wooden frame. At the summit of the rod A is a large ball C, through which the brass rod D C passes, having a ball at each end. This rod is capable of moving in a vertical circle, being delicately balanced upon knife-edges within the ball C; F is another ball supported by a brass wire fixed into C. G is another brass ball communicating by a chain, with one side of the jar or battery, while C communicates with the opposite side by means of the chain H. K is a small slider which moves along the graduated arm C E, and measures the weight in grains, which, if placed at E, will cause the arm and ball E to descend to G. When the chain H communicates with one side of a jar, and the chain from G with the other side, it is obvious that no discharge

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can take place until the ball E shall descend upon the ball G; and therefore, by the adjustment of the slider K, the charge may be compelled to continue to increase, until the force exerted shall be equal to any required number of grains upon the scale of the instrument.

As far as experiments have hitherto proceeded, it would appear that this instrument is a tolerably accurate measure of the intensity of electrical charge upon two coated surfaces of given extent, and having a non-conductor of given thickness interposed between them. The following results are cited by Mr. Singer in proof of this supposition. Two inches of steel wire, employed for making the hair spring of a watch, were fused, by being placed in the circuit, through which the discharge of a jar passed with the beam of Cuthbertson's electrometer, loaded to fifteen grains. The same jar was capable of fusing eight inches of the same wire, with the charge which it acquired by loading the beam with thirty grains. If, instead of increasing the weight beyond fifteen grains, two such jars be employed, the eight inches of wire are fused as in the last case. Hence it would appear, that it is the same thing, whether the intensity of the electricity be doubled, or the extent of the coated surface.

Chap. V.

Chap. VI.

CHAPTER VI.

Effects of electricity upon organic and inorganic matter, and also upon the other imponderable physical agents.

In arranging the subordinate divisions of this chapter, considerable difficulties must be encountered, arising from the imperfection of our knowledge, both of our effective agent, and of the subjects upon which we suppose its action to take place. We are frequently unable to distinguish accurately between cause and effect. If we pass a powerful electrical charge through a small metallic wire, the metal may be heated to redness, or whiteness, or may be fused, or even volatilized. Heat then is produced; but from whence? Did it exist originally in the metal, and was it forced out by the violent mechanical action of a material fluid passing through the wire? or is it the electric fluid, again appearing under some new modification of form? Arguments might be found in favour of each of these views, but this is not the place for their appearance. When an electrical machine is in powerful action, there is a peculiar smell something similar to that which is produced by the friction of two pieces of quartz upon each other; but how electricity should thus affect our sense of smelling, we are unable to tell. Amidst difficulties such as these, which meet us at every step we take in physical inquiry, we propose to arrange the subjects of this chapter under the following sections.

§ I. Effects of electricity upon inorganic matter, comprising those which are purely mechanical.
§ II. Effects of electricity upon vegetable life.
§ III. Effects of electricity upon animal life.
§ IV. Effects of electricity in the production of chemical composition and decomposition.
§ V. Effects of electricity in the developement of light from phosphorescent bodies.
§ VI. Effects of electricity in the evolution of heat.
§ VII. Effects of electricity upon magnetic bodies.

§ I. *Effects of electricity upon inorganic matter, comprising those which are purely mechanical.*

Mechanical effects.

(143.) To be enabled to give a specific account of those electrical effects which are purely mechanical, we ought in the first place to know whether electricity be a material fluid or not; and as we have acknowledged our inability to satisfy the inquirer upon this point, we can only venture to class together a few phenomena which seem to be most easily explained upon the supposition of material and mechanical agency.

Lateral expansion of metals

The power of an electrical discharge to heat substances of considerable conducting power in its passage through them will be examined hereafter; but it would seem that in all such cases there is either a great and permanent expansion, or which perhaps amounts to the same thing, a separation of the particles of the body through which the discharge takes place. Thus, it was observed by Dr. Priestley that a chain through which an electrical discharge had passed, had suffered a diminution in its length. Upon a more accurate trial, he found that a chain twenty-eight inches long, lost a quarter of an inch of its length by the passage of a charge through it from 64 square feet of coated surface. Mr. Nairne passed the charge from 26 square feet of coated surface repeatedly through a piece of hard drawn iron wire 10 inches long and $\frac{1}{100}$th of an inch in diameter. The wire was examined after the sixth, ninth, and fifteenth discharges, and it was found to have lost about $\frac{3}{40}$ths of an inch of its length by each shock. The total contraction was fully one inch and $\frac{1}{10}$th. No perceptible loss of weight could be discovered, but the increase of thickness seemed to be in proportion to the longitudinal contraction the wire had undergone. It appeared also, that a copper wire plated with silver, and of the same dimensions as the iron wire before employed, underwent a diminution of length only $\frac{2}{3}$ds as great as had been suffered by the former wire.

Mr. Brooke passed the charge from 16 square feet of coated surface, nine times successively through a steel wire 12 inches in length and $\frac{1}{100}$th of an inch in thickness, and thus produced a longitudinal contraction of one inch and a half.

(144.) It may easily be conceived that whenever the electrical discharge takes place through more imperfect conductors, its progress will be marked by still greater violence of effect: and it appears that even the most perfect conductors with which we are acquainted, if they have not sufficient magnitude for the free transmission of the discharge, suffer from the passage of the fluid, in a manner similar to imperfect conductors of greater volume. For the convenience of the young electrician, the following illustrations of this species of action are arranged in a series of experiments, which it will not be found difficult to repeat.

(145.) *Exp.* Let a capillary tube, such as is employed for the stem of a thermometer, be filled with mercury, and let this mercurial thread form part of the circuit in an electrical discharge. In this case although the conductor is excellent, it will undergo so great an expansion as to burst the glass tube in which it is contained.

(146.) *Exp.* If a substance of inferior conducting power be employed, its volume may be considerably increased, and the same effect will still be produced. Thus "insert two wires through corks in the opposite ends of a small glass tube, let the distance of the ends of the wires be half an inch; fill the tube with water, and pass a moderate charge through it; the tube will be broken and the water dispersed." Singer.

"The expansion of fluids by electricity is indeed very remarkable and productive of some singular results. When the charge is strong, no glass vessel can resist the sudden impulse. Beccaria inserted a drop of water between two wires in the centre of a solid glass ball of two inches diameter; on passing a shock through the drop of water, the ball was shattered with great violence. Mr. Morgan succeeded by the same means in breaking green glass bottles filled with water, when the distance between the wires that conveyed the spark and the sides of the glass exceeded two inches." (Singer.) The same author states that, "with but a moderate charge he has in that way broken glass tubes the thickness of half an inch in the sides, and having a bore of the same diameter."

(147.) *Exp.* "Drill two holes in the opposite ends of a piece of wood which is half an inch long and a quarter of an inch thick: insert two wires in the holes, so that their ends within the wood may be rather less than a quarter of an inch distant from each other; pass a strong charge through the wires, and the wood will be split with violence. Loaf sugar, stones, and many other brittle non-conductors may be broken in the same way, if a sufficiently powerful charge be employed."

(148.) *Exp.* Introduce two wires into a soft piece of pipe-clay, and pass a strong shock through them: the clay will be curiously expanded in the interval between the wires. This experiment will not be successful if the clay be either too moist or too dry.

(149.) *Exp.* Place a piece of plate glass about an inch square and half an inch thick, flat upon the small table of the universal discharger, and press it by a weight. Set the points of the sliding wires opposite to each other, and against the under edge of the glass, so that the spark may pass beneath it: the charge of a large jar transmitted in this way rarely fails to break the glass.

(150.) *Exp.* Let a spherical cavity be turned in a piece of ivory, capable of receiving the half of a light wooden ball; a small conical cell is to be made at the bottom of the spherical cavity, and two wires inserted through the sides of the mortar into it: if a drop of water, oil, alcohol, or ether be put between the wires, and the ball placed over them in its cavity, a charge sent through the drop of fluid will convert part of it into vapour, and expel the ball with considerable force. Beccaria; Lullin.

(151.) If an electrical discharge be passed over the surface of a piece of dough, its course will be marked by an irregular line or indentation. If over ice, the surface is sometimes marked with spots, as if a hot chain had been laid upon it. If over snow, a channel is furrowed out upon its surface. If through a piece of paper, or a green leaf, the substance is rent in the direction of the discharge.

(152.) Several experiments have at different periods been brought forward as evidence of the materiality of the electric fluid, or as affording proof of the existence of one fluid by showing in what direction motion is produced at the instant of a discharge. A light ball has been made to move along a groove, between the two balls of a discharger, or a wheel has been made to revolve, by presenting the extremities of its radii to an electrified point, but we feel little inclined to occupy our pages with experiments of this nature, as we are convinced that all these cases are easily explained by taking into consideration the ordinary effects produced by attraction in our atmosphere.

(153.) There are however some singular appearances presented by substances through which electrical discharges have proceeded, which it will be accordant with our plan to introduce under the present section.

If a considerable electrical discharge from a Leyden jar be passed through a card or a quire of paper, there will appear a sort of bur as if some expansive effect had taken place, or some body had passed from the centre towards the two external surfaces of the plane; but it is said, that the larger protrusion will be found upon the resinous side of the plane, which fact has been brought forward as a proof that there is but one fluid which at the instant of the discharge, passes from the positive to the negative surface of the jar. Mr. Symmer upon a careful examination of these appearances, was convinced of the existence of two currents which had passed in opposite directions through the quire of paper, and had left a hole such as would have been produced by drawing two threads through, in opposite directions. (*Phil. Trans.* 1759.) To the same gentleman we are indebted for the following variation in this experiment: Let a slip of tin-foil be placed in the midst of a quire of paper; and within another quire of paper let there be two slips of tin-foil, separated by the two middle leaves of the quire. By passing a strong shock through each of these quires, different effects will be produced. In the former, the tin-foil will have received two indentations in opposite directions, and the leaves of paper will be rent in such a manner that on both sides of the tin-foil the burs shall point toward the outsides of the quire; but the indentations upon the foil, and the burs in the paper will be in opposite directions. In the other quire, all the leaves will be perforated, excepting the two between the tin-foil, and these two will have received indentations in opposite directions.

(154.) Even if we were to admit that the effects thus produced upon paper, pasteboard, or soap, do prove the passage of the discharge to proceed from the positive to the negative side of the jar or battery, there does not appear any absurdity in supposing that the vitreous electricity should have the power of proceeding under certain circumstances, with the greater velocity to form a union with the resinous fluid. It appears in fact that these motions are influenced in some way or other by the state of atmospheric pressure; for let a varnished card be suspended by silk,

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in such a manner that two blunt wires proceeding from the opposite sides of a battery may be in contact with the opposite surfaces of the card; but so that the points although in contact with the card are half an inch distant from each other. When the discharge of the battery has taken place, the card will be found perforated, but always at the point where the resinous wire touches it, even if a hole be previously made against the point of the wire from the vitreous side of the battery. Clearly then, in this case, the fluid passes from the vitreous to the resinous conductor.

In the next place let all conditions remain the same, and let the experiment be performed under the receiver of an air-pump. It will be found that in proportion as the pressure of the air is removed, the perforation will be made nearer to the vitreous conductor. Hence it would appear that in rarefied air the negative electricity is capable of advancing to meet the vitreous electricity, and that in general the air exerts a greater coercive force upon the former than upon the latter fluid. Tremery, *Journal de Physique*, liv. p. 357.

This passage of the charge from the vitreous to the resinous surface is easily perceived in a darkened room, and some instances of this kind have already been noticed, (89.) and (90.) M. Charles rendered this motion very apparent, by covering long pieces of black cloth with metallic spangles or filings, so that the interruption of continuity in the circuit, made the time and therefore the direction of the discharge very perceptible.

(155.) From the instances which we have already brought forward of powerful mechanical effects produced by the passage of an electrical discharge through an imperfect conductor, we are in some degree compelled to recognise electricity as a material fluid; but if so, how extraordinary must be the velocity of its movements. Its weight is to us inappreciable, and yet by its momentum it can rend and disperse the densest metals, and from this circumstance alone, reasoning upon the universal laws of mechanical force, the velocity must be immense.

(156.) *Exp.* Let a strip of gold or silver leaf, or Dutch metal be gummed to the surface of a piece of paper, and so arranged between the forceps of the universal discharger that an electrical charge may be passed through it. No portion of metal will afterwards be found; part is seen to be dispersed in a sort of vapour, or perhaps very minute powder, and part remains in a state of oxidation upon the paper, which thus receives a greenish brown colour.

(157.) *Exp.* "Take three pieces of window-glass, each an inch wide and three inches long, place them together with two narrow strips of gold-leaf between them, so that the middle piece of glass has a strip of gold on each of its sides; the extremities of the gold strips should project a little beyond the ends of the glass: pass the charge of a large jar through the gold strips, they will be melted and driven into the surfaces of the glass. The outer plates of glass are usually broken, but that in the middle frequently remains entire, and is marked with an indelible metallic stain on each of its surfaces."

At the same time that these violent dispersive effects are produced, the developement of heat and chemical combination also takes place. Of these we shall speak hereafter, but this dispersion of so heavy a metal as gold leads to the following singular speculation. Gold is about nineteen times specifically heavier than water, and the volume of water in the state of vapour, is 1600 as great as in its liquid state. Let us suppose it necessary that the vapour of gold shall be compelled to assume the same density as the vapour of water. In this case the filament of gold-leaf in the process of volatilization, must undergo an expansion of volume equal to nineteen times 1600, or become 30,400 as great in its solid state.

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Some recent experiments seem to prove that the two electricities exert opposite actions upon the molecules of matter, under circumstances favourable to crystallization, and that this process is assisted by the presence of resinous electricity. As these researches have been made with the voltaic pile, we must reserve a more specific account of them for their appropriate situation under the article devoted to that modification of electrical action.

When an electrical discharge takes place in the air, whether it be a spark or from the more abundant accumulation of a shock, a report is heard; and this report has we think been satisfactorily explained on a common mechanical principle. "The sound is produced by the sudden collapse of the air which has been displaced by the passage of the electric fluid; and it is consequently greater in proportion to the quantity and intensity of the charge. Hence when different sized jars have been charged to the same degree, (of intensity,) and then successively discharged, the explosions produced will be louder in proportion as the jars are larger; and the effect afforded by a battery of extensive surface will be that of a comparatively violent effort." Singer, p. 147.

Lichtenberg.

(158.) There is an elegant illustration of electrical attraction, for which we are indebted to Professor Lichtenberg of Göttingen, which has also been considerably modified and improved by more recent electricians.

Exp. Take a smooth disc of resin, or the lower plate of an electrophorus, and trace any lines over its surface with the knob of a jar charged with vitreous electricity; and then repeat the same with a jar charged with the opposite fluid. By means of one of the old-fashioned powder puffs or some similar contrivance, project over the surface of the disc a mixture of finely powdered sulphur and red lead, triturated together in a mortar. By the friction thus produced, the sulphur will have acquired vitreous, and the minium, resinous electricity; and each substance when projected upon the disc will attach itself to the oppositely electrified lines, forming a series of red and yellow outlines. These are the figures of Lichtenberg, produced in the most simple manner; but other and far more complicated varies of the experiment may be found by the following references. Lichtenberg, *Nov. Com.* Gotting. 1777, vol. viii. p. 168; Bennet, *New Experiments in Electricity*, 8vo. Lond. 1789.

On the subjects of this section consult Symmer, *Phil. Trans.* vol. li. p. 371; Beccaria, *Lettere dell' Ellettricismo*, p. 74; Cavallo, *Phil. Trans.* 1780, p. 15; Priestley's *Hist. Elec.* p. 672; Ingenhouz, *Phil. Trans.* 1778, p. 1022; Nairne, *Phil. Trans.* 1780, p. 334; Gough, Nicholson's *Journal*, vol xxxiii. p. 176; E. Walker, *Phil. Mag.* xlii. p. 161; Singer's *Electricity*, p. 167; Berlinghieri, *Jour. de Phys.* xl. p. 133; Lullin's card, Nicholson's *Jour.* viii. p. 223

§ II. *Effects of electricity upon vegetable life.*

Effects on vegetables.

(159.) The first experiments upon the application of electricity to living vegetables, were made by Mr. Maimbray of Edinburgh, in October 1746. It appeared that two myrtle trees which had been subjected to gentle electrical action during the month of October, put forth leaves in the subsequent spring, earlier than similar trees which had not been electrified.

Nollet.

The Abbé Nollet supposed that he had fully verified these results, and his experiments were repeated and varied by MM. Jallabert, Boze, the Abbé Menon, Dr. Carmoy, the Abbé D'Ormoy, and the Abbé Bertholon, who all conceived that they had found electricity to produce beneficial effects upon the growth of living vegetables. Of these experimentalists, the Abbé Bertholon was by far the most sanguine, and appears to have been most erroneous in his conclusions. It would be a waste of both time and space which we can devote to better purposes, if we should here attempt to describe the extensive system of electrical horticulture proposed by this author. The whole depended upon the elevation of pointed conductors to a considerable height in the air, by which means a supply of electricity was to be obtained, and again dispersed from a series of points over the growing produce of the garden.

Ingenhouz

A very elaborate series of experiments by Dr. Ingenhouz, in which the processes of preceding writers were repeated and examined, appeared in 1778, and entirely changed the current of opinions upon this subject; and Mr. Cavallo, who appears to have made similar experiments, expresses his complete conviction of the inefficacy of electricity as a stimulus to vegetable life.

Van Marum.

Van Marum wished to ascertain whether the sensible perspiration of vegetables were increased by electricity. He therefore insulated the vegetables growing in flower pots, and brought them in contact with vitreously electrified conductors. After being thus exposed to electricity for a quarter of an hour, the loss of weight by evaporation was found to be in some $\frac{1}{4}$th and in others $\frac{1}{3}$d more than in the unelectrified state. It is possible that even here there may be some deception; for as every pointed electric conductor propels from itself a current of air, so must the points of the leaves of plants; and the constant succession of fresh portions of air by means of this current must tend to increase the quantity of evaporation.

Dr. Van Marum also examined the influence of electricity upon the sensitive plants. He first exposed the *Mimosa Pudica* to the sun, in order that its leaves might be fully expanded, and then brought it successively within two feet of a vitreously electrified conductor, and of one resinously electrified. By neither of these methods was any effect produced. The plant being placed upon the conductor, the small leaves raised themselves up a little and expanded, when no sparks were drawn from the conductor; but as soon as sparks were taken from the conductor, the small leaves again fell nearly in the same manner as the pendulum electrometer. After a few such changes they at length began to approach each other, to close themselves, and became totally shut. This result took place also in consequence of other kinds of concussions, and therefore must not be ascribed exclusively to electricity. In other respects the plants underwent no change.

In experiments of the same kind made with the *Hedysarum Gyrans*, the electricity produced neither acceleration nor retardation in the movements of the small leaves.

(160.) Such is the information we possess upon the effect of feeble electricity applied for a long time to growing plants, or only applied for a short time to plants which seem to possess great nervous irritability. If however the electricity be applied with greater violence to living vegetables, very decided destructive effects are produced.

Mr. Nairne, in the year 1773, made some experiments of this sort upon different plants, particularly myrtles and laurels. Van Marum, who has most recently examined this subject, made choice of much more vigorous trees, such, for example, as the young stems of the common willow, and in the middle of April, a period at which the young branches usually shoot forth. Through two of these, eight feet in length, he conveyed shocks; to the first, through a space of 15 inches in length; and in two others, through their tops only. After the passage of these shocks the trees were planted; but the parts through which the shocks had been conveyed sent forth no branches. The upper parts through which the shocks had passed, sent forth a few shoots for some days, but very slowly, and these shoots shortly withered and died. Those parts not electrified sent out branches, like the other trees planted near them.

Mr. Cavallo also mentions the very easy manner in which the "Balsam (*Impatiens*) is killed by means of electricity. The plants of that genus are not remarkably delicate, they grow easily, their stocks and branches are thick in proportion to the size of the plant, and they bear the inclemency of the weather tolerably well; yet a very small shock sent through the stem of a balsam is sufficient to deprive it of life. A few minutes after the passage of the shock, the plant will droop, the leaves and branches become flaccid, and, in short, its vegetation is quite destroyed. I have, indeed, known some plants of that species which have revived after a day or two; but that effect seldom takes place. A small Leyden phial, such as may contain six or eight square inches of coated surface, is sufficient for this purpose; and it may even be effected by means of strong sparks from the prime conductor of a large electrical machine.

"In this experiment neither the internal vessels, nor any other part of the plant, appears to be injured, and indeed the size of the plant, and the inconsiderable strength of the shock which is used, are such as not to indicate the possibility of the vessels being burst, or of the vegetable organization suffering any material derangement; it would, therefore, be useful to investigate the immediate cause which occasions the death of the plant.

"Having subjected several other plants to the action of electric sparks and shocks, I have not found any that can be so materially hurt by an electric power, so small in proportion to its size, as that which is sufficient to destroy the vegetation of a balsam." Cavallo, vol. iii. p. 249.

On the whole, then, as far as experiments at present warrant our decision, feeble electricity exerts no perceptible influence upon vegetable life; but its more violent effects are similar in their destructive nature to those produced by lightning.

Consult Browning, *Phil. Trans.* 1747, p. 373; Nollet, *Recherches sur les causes particulières des Phenomènes Electriques*, p. 356, Paris, 1749; Kies and Kostelin, *De effectibus Electricitatis*, Tubingen, 1775; Ingenhouz, *Jour. de Phys.* xxxii. p. 321, and xxxv. p. 81; also Ingenhouz, *Versuche mit Pflanzen*, 1790; Crell, *Jour. de Phys.* xxx. p. 157; De Rozieres, *Jour. de Phys.* xxxviii. p. 351; Carmoy, *Jour. de Phys.* xxxiii. p. 339; Rowland, *Jour. de Phys.* xxxv. p. 3; D'Ormoy, *Jour. de Phys.* xxxv. p. 161; Bertholon, *Jour. de Phys.* xxxv. p. 401; De Rozieres, *Jour. de Phys.* xxxviii. p. 351—427; Chappe, *Jour. de Phys.* xl. p. 62; Mauduyt, *Jour. de Phys.* xl. p. 241; Bertholon, *De l'Electricité des Végétaux*; Van Marum, *Tweede Vervolg der proefnemingen gedaan met Teylers Elect. Mach.* 4to. Haerlem, 1795; or an abstract in *Phil. Mag.* 1801, p. 193, 313.

§ III. *Effects of electricity upon animal life.*

The facts to be brought forward in the present section, will form an abstract of the best authenticated electrical experiments upon living animals, both in the states of health and disease, and will therefore slightly touch upon that branch of the science which is termed medical electricity.

(161.) The sensation produced by receiving a spark upon any part of the body; and the more powerful one experienced when we form part of the circuit through which the charge from the two sides of a coated jar returns to the state of electrical equilibrium, must be familiar to every one; and the latter is, with good reason, called the electrical shock.

We are not sufficiently acquainted with the nature of that subtle agent, upon which we now treat, to give a satisfactory reason for this singular and violent effect upon all bodies through which the discharge passes. We know not whether in the human frame, the concussion and involuntary muscular motion, be produced merely by an influence upon the nervous system, or by the passage of a subtle, but material, fluid through the substance of our bodies; or by the sudden decomposition of the natural electricity of our frame for the purpose of neutralizing the accumulated masses of the opposite fluids disposed upon the two coated surfaces.

Mr. Morgan states, that if the discharge from two square feet of coated surface be made to pass through the region of the diaphragm, a sudden convulsive action of the lungs produces a loud shout; but that, if the charge be much smaller, it produces a violent fit of laughter, even in the gravest persons. A very strong charge passed through the diaphragm, produces involuntary sighing and tears, and sometimes brings on a fainting fit.

There appears to be some difference in the effects produced by shocks of the same actual intensity, if received by different persons; and it seems that persons of great nervous irritability are affected more violently than those of a more phlegmatic temperament. Mr. Cavendish proved experimentally what our theory would lead us to suppose; that the sensation produced by a shock depends upon the quantity of the electricity, rather than upon its intensity. That a given extent of coated surface, charged to a certain degree of intensity, gave a perceptibly greater shock, than half that extent, charged to a degree of intensity, double of that in the former case. Dr. Robinson, however, states, that a charge of low intensity, received from a large extent of coating, is less disagreeable than one of very high intensity, from a much smaller surface. In this case, however, there is no estimate of the relative quantity of electricity in each case; and it does not seem at all improbable that where the same quantity of electricity is disposed upon the coatings of two jars, the one small, and the other large, the increased intensity of the electricity upon the smaller jar, will cause the discharge to take place with greater rapidity, and consequently with greater perceptible violence of action.

(162.) In our historical introduction, we have related the splendid discovery of Franklin, by which he identified the electricity of the experimentalist with the lightning of the atmosphere. Among other proofs of that identity, history afforded numerous instances of persons who had been killed, during thunder storms, by a stroke analogous to the discharge of an electrical battery; and the death of the unfortunate Richman by a discharge of electricity which he had conducted from the clouds to his own apartment, was a confirmation, (had any such been necessary,) and at the same time a warning to all subsequent electricians. The same system of action which produces the sensible shock, seems, if carried to excess, to be instantly destructive of animal life; and the fact of a pigeon, having lost its sight from the passage of a shock through the head, lends a degree of probability to the supposition, that the destruction of nervous irritability is the immediate cause of the death of the animals.

In attempting to investigate the nature of this destructive action, Dr. Van Marum made several experiments. "For this purpose he employed eels, which, as is well known, even when cut into three, four, or six parts, and when deprived of the head, still retain signs of irritability. These eels were a foot and a half in length, and the shock was conveyed through the whole body. By these means they were instantly killed, and never moved afterwards. They were immediately skinned, and trial was made by pinching, pricking, &c. whether any irritability remained; but no traces of any were perceptible, even when pretty large sparks were drawn from these parts. The strongest salts were attended with as little effect.

"When the shock was made to pass through individual parts, for example the head, these alone lost their irritability, while the rest retained it. When the head was kept free from the shock, the remaining parts only were paralysed. The same experiments were several times repeated on eels $3\frac{1}{2}$ feet in length, and with the same results. When the shock was made to pass through the upper and fore part of the head of large eels, the under jaw, as well as the muscles of the neck and belly, and even the lower part of the body, retained their irritability, while it was completely destroyed in the parts through which the shock had passed. The same effects were produced in warm-blooded animals, for example rabbits, with much smaller batteries." Nicholson's *Jour.* viii. p. 319.

(163.) It had been remarked that whenever animals had been killed by lightning, the process of spontaneous putrefaction ensued with unwonted rapidity. This circumstance has been examined by M. Achard, of Berlin. The following is an abstract of his Paper upon the subject.

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city.

"It is a well known observation, that after a storm, flesh, either raw or boiled, acquires a putrid smell, which in the latter is particularly acid. It is known, also, that grain suffered to ferment for the purposes of brewing or distilling, undergoes, during stormy weather, very sudden and perceptible changes. On such occasions it is often extremely difficult to observe where the first degree of fermentation ceases, as it passes so speedily; and the second degree, or the acetous fermentation, takes place before one is aware. To ascertain, therefore, whether the electric matter, which during stormy weather is so abundant in the atmosphere, has any share in these phenomena, the following experiments were made.

"A piece of raw beef was cut into three parts. One of these parts was electrified positively for ten hours without any shock; a second was electrified negatively for a similar time; and the third was not electrified at all. The three pieces were left in the same apartment, exposed to the same degree of heat. When examined next day, both the pieces which had been electrified appeared to be tender, but were free from the least bad smell. On the fourth day the electrified flesh had an intolerably fœtid smell, and that which had not been electrified began to smell a little.

"M. Achard repeated these experiments with boiled veal. That which was electrified had, the next day, an acid smell, and an unpleasant taste; but that which had not been electrified, continued sweet for three days, and only on the fourth day began to have an acid smell.

"Several birds were killed by electric shocks, and others were deprived of life by sticking a needle through their heads, and then placing them all in the same temperature; they were covered with glass receivers in order to preserve them from insects. Observing the gradual progress of corruption in both sets, M. Achard plainly perceived that it took place much sooner, and advanced more rapidly in those killed by electric shocks, than in those deprived of life by the needle. In those also, to which a stronger shock had been given, the degree of corruption was far greater than in the others; and the cause in all probability was," (according to M. Achard's opinion,) "that in this case the vessels containing the animal fluids were suddenly destroyed, by which means these fluids had diffused themselves through the particles of the body, and might thus accelerate putridity.

"It clearly follows from these experiments, that electricity accelerates corruption, and that the putrefaction of flesh after a storm, must be ascribed solely to the more abundant accumulation of the electric matter at that time. M. Achard saw that this was the case in regard to several persons killed by lightning. The body of a farmer, who lost his life in this manner, between five and six o'clock in the evening, emitted next morning a very perceptibly fœtid smell, which in the evening was totally insupportable."

Medical electricity.

(164.) We have already, in the historical introduction to this article, made sufficient mention of the fraudulent or mistaken attempts made by Pivati to exalt electricity to the rank of a sovereign remedy for all disorders. Philosophers had before them an agent of subtlety almost unexampled, and which traversed the human frame with unmeasured and irresistible rapidity, which affected the nervous and muscular system in a manner which it was beyond the power of volition to controul; and it was neither absurd nor unreasonable to suppose that such an agent might, under some modification, produce a salutary effect upon the diseases to which mortality is liable.

They who first proposed the medical application of electricity seem to have entertained mistaken notions of the mode of its action; and consequently, to have erred in their calculation of the effects which it was expected to produce. They conceived that it was to operate as instantaneously upon disease, as it did upon the sensations or muscular powers of the animal frame; forgetting that there are very few cases in which a system of depraved vital action can instantaneously be changed into a healthy discharge of the functions of life. The pretended results of Pivati were refuted by Bianchini and Nollet, and the errors of Winkler were corrected by Watson and others. Several years after these events, the Abbé Bertholon published a work in two volumes, *De l'Electricité du corps humain dans l'état de Santé et de Maladie*. (1785.) This treatise is fanciful in the highest degree, and ascribes considerable influence to the electric fluid of the atmosphere, in regulating the number of births, deaths, and sicknesses which prevail among mankind.

Approaching, however, to a more respectable era in the history of medical electricity, we find careful experiment the only allowed guide in applying electricity to the relief or cure of disease. Mr. Trembley had communicated to the Royal Society, that many persons had found that while they were electrified, the rapidity of the arterial pulse was increased. The same position was maintained by M. Boze; and the Abbé Nollet, whose candour and abilities as an experimentalist have never been impeached, applied himself to diligent researches connected with this part of our subject. Reasoning upon the increased rapidity with which water escaped through a capillary tube, when in an electrified state, he considered that all animal and vegetable bodies were made up of capillary tubes, through which the nutritive fluids were conveyed, and thence inferred that electricity would increase the rate of the circulation and promote perspiration. His experiments, however, led him to the following conclusions: That the constant communication of electricity to a living animal for a considerable time, did increase the quantity of perspiration. These results were obtained from birds, cats, and the human subject. In all cases, pairs of the animals
were selected and carefully weighed; after a curren
of electricity had been conveyed to them for som
hours, they were again weighed, and all loss was a
tributed to perspiration: The electrified animal w
always found lighter than the one which had
been so acted upon. No inconvenience whatever
felt by the persons who submitted to these exp
ments. They only found themselves a little exhau
and had gained an appetite. None of them f
themselves sensibly warmer, neither could the
perceive that their pulse was increased.

The comparatively recent experiments of D
Marum are, however, considered more conclu
some of these points. With regard to the e
electricity upon the pulse. Eleven perso
selected, and the experiment was repeated fo

upon each, both with positive and negative electricity. "These persons were placed in a room which was at such a distance from the machine that they could not hear the noise it made in turning; they were insulated, and the pulse of each was felt when the machine was in motion, as well as when it was at rest, (which last circumstance was unknown to them,) and the beats were counted by a good observer, provided with an excellent watch. In some cases a few beats more were observed, but, on the whole, there was no important acceleration. In general, however, there was great irregularity in the pulse, both during the time the persons were electrified, and during the time the machine was at rest."

For the purpose of ascertaining "the increase of insensible perspiration, Van Marum employed a very delicate balance; one scale of which was insulated by means of a silk cord. On this scale he placed a boy, eight years of age, connected with the conductor; and the balance was brought to a state of equilibrium. He then ascertained the loss of weight sustained in half an hour, before the boy was electrified, and found it to amount to 280 grains. By a similar experiment on another occasion, the loss of weight, before being electrified, was 330; and after exposure to electricity only 310 grains. A girl of seven years old lost, before being electrified, 180; and when electrified 165 grains. A boy of eight years and an half lost, unelectrified, 430; and when electrified 290 grains. Another of nine years unelectrified 170, electrified 240. As the last boy was exceedingly quiet during the experiment, it was thought that the increase was the consequence of electricity; on this account he was several times subjected to the experiment, and the results were: In the unelectrified state 550; in the electrified 390, 330, 270, 550, and 420. In most of these experiments, it appeared that there was rather a decrease."

It has, however, been stated by Mr. Cavallo, that a medical electrician of considerable experience, assured him, "that in a diseased state of the body, an evident acceleration of the pulse is often observed to result from the application of electricity." Mr. Carpue mentions, that having opened a vein from which the blood did not readily flow, he electrified the patient, and the blood then streamed forth freely.

(165.) The following passages are selected from Mr. Singer's work, because, with the opinions and expectations there advanced, we are inclined fully to concur.

"The scientific application of electricity to medicine, has made less progress than the success which has attended it might have been justly expected to produce. It appears from almost every trial of its power hitherto made, that under judicious management its application can do no harm, and that in many of the most distressing disorders, it has frequently been of considerable service. These are powerful recommendations, and when it is added, that it is an external, and by no means painful remedy; and that it may be applied immediately to the affected limb, without interfering with any other part, its advantages must appear to be considerable.

"The machine employed for medical purposes should have sufficient power to furnish a constant stream of strong sparks, for in many cases an application of that kind is essential. If it is a plate machine, the diameter of the plate should not be less than from eighteen inches to two feet; if it is a cylinder, the diameter may be from eight to fourteen inches.

"The auxiliary apparatus is very simple; the most essential instruments are: 1st, a jar fitted up with Lane's electrometer, fig. 86, by which shocks of any required force may be given; 2d, a pair of directors, fig. 8 and 9. Occasionally one of the brass balls may be unscrewed, and a wooden point substituted for it. When shocks are passed by the aid of these directors, they are applied at the opposite extremities of the part through which the charge is to pass; and being respectively connected by conducting wires, the one with the outside of the jar, and the other with the receiving ball of Lane's electrometer, previously placed at the required distance, the jar may be set to the machine, which is then put in motion, until any required number of shocks has been given.

"The insulated director is employed also to give sparks, being held by its glass handle, and its ball previously connected with the conductor by a flexible wire; being brought near the patient, or rubbed lightly over a piece of flannel or woollen cloth laid on the affected part. When the eye or any delicate organ is electrified, the ball of the insulated director is unscrewed, and the wooden point applied at the distance of about half an inch from the part. The stream of electrified air, which passes from the point under such circumstances, produces rather a pleasant sensation. Very excellent flexible conductors for medical purposes, may be made by sewing a thin spiral brass wire, (such as is used for braces,) within a thick silk riband.

"The insulating stool employed, should be of sufficient size to receive a chair upon it, with a resting-place in front of the chair for the feet. The patient being placed on the insulated chair, and connected with the conductor of the machine, becomes a part of it, and sparks may be drawn from any part of the body by a person who stands on the ground and presents a brass ball to it. If the ball is held by a wooden handle, the sensation is less painful than when it is held by metal."

We may perhaps be thought to enter too minutely into this branch of our subject; but should this be urged against us, we would plead, that electricity, as a medical agent, has not yet had a full and fair trial, such as to enable the practitioner at once to predict whether in any proposed case it will be a sanative or inert application. Further, that it has never been known to produce consequences decidedly injurious; and that as it is a remedy of such a nature that a long continuance of its application is in most cases necessary, it becomes desirable that ample instructions should be given, to enable any one to apply it with security and ease.

The most respectable and most recent collection of cases to which electricity has been applied, is to be found in a very candid little work on the subject, by Mr. Carpue. We feel that we are unable to improve upon the following abstract of its contents made by Mr. Singer, and arranged under the disorders operated upon.

1. *Contractions.* Those that depend upon the affection of a nerve only; and in many of these it has been employed without effect, whilst in others, of long duration, immediate relief has been obtained.

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2. *Rigidity.* Very frequently relieved, but usually requiring some perseverance in the application to complete the cure.

3. *Sprains, relaxation, &c.* Electricity may be applied in all these cases with good effect, but its application should be deferred until the inflammation has subsided.

4. *Indolent Tumours.* Strong sparks and slight shocks are often effectual. The most numerous cases are those of *scirrhous testes;* and there are some instances of the successful dispersion of *scirrhous induration* of the breast. Ganglions have also been removed from the wrists or feet by the frequent application of sparks.

5. *Chilblains.* Mr. Carpue states that electricity is a good preventive against chilblains, and mentions two instances in which they were removed by the action of electrical sparks.

6. *Epilepsy.* In several instances of persevering application, not one successful case occurred.

7. *Deafness.* Sparks thrown upon the *mastoid process,* and round the *meatus auditorius externus,* and drawn from the same parts on the opposite side, usually afford relief; and about one in five are permanently cured.

8. *Opacity of the Cornea.* This is sometimes cured by the long continued action of electricity thrown for ten minutes a day on the eye by a wooden point. When caused by the small pox it is said to yield most readily. Mr. Singer also mentions an instance in which considerable benefit was received from the application of electricity; but its use could not afterwards be discontinued for more than a week at a time without a return of the disorder.

9. *Gutta Serena.* The method of electrifying for *opacity of the cornea* has been successful in some instances of *gutta serena;* but there are very many unsuccessful cases.

10. *Amenorrhea.* Cases of this nature are generally relieved by sparks and slight shocks; but in retention electricity has been tried without success.

11. *Knee Cases.* In instances of pain and swelling of the knee the application of sparks has been effectual in about one case in ten.

12. *Chronic Rheumatism.* Very numerous are the instances of success, the usual application is by sparks for ten or fifteen minutes every day. In recent cases a few days sometimes suffice, but in those of long standing very considerable perseverance is often required.

13. *Acute Rheumatism.* In one case out of six a cure was effected in about a month by the application of the electrified current of air from a point.

14. *Paralysis.* Moderate shocks, with sparks occasionally, have been successful in about one case of paralysis in every fourteen that have been tried.

15. *St. Vitus' Dance* has also been frequently relieved by electricity. There is, indeed, scarcely any disease in which some successful instances of its application are not recorded; but we are still in want of a scientific examination of the statements that have been made on this subject. Singer, p. 295.

For further information relating to this section, consult De Boze, *Phil. Trans.* 1745, p. 419; Miles, *Phil. Trans.* 1746, p. 78; Winkler, *Phil. Trans.* 1746, p. 211; Winkler, *Phil. Trans.* 1748, p. 262; Browning, *Phil. Trans.* 1747, p. 373; Watson, *Phil. Trans.* 1751, p. 231; Baker, *Phil. Trans.* 1748, p. 570; Hart, *Phil. Trans.* 1754, p. 786; Id. 1755, p. 558; Brydone, *Phil. Trans.* vol. l. p. 392; Franklin, *Phil. Trans.* vol. l. p. 481; Brydone, *Phil. Trans.* vol. l. p. 695; Himsel, *Phil. Trans.* vol. li. p. 179; Watson, *Phil. Trans.* 1763, p. 10; Spry, *Phil. Trans.* 1767, p. 88; Partington, *Phil. Trans.* 1778, p. 97; Fothergill, *Phil. Trans.* 1779, p. 1; Kies and Koestlin, *de Eff. Elect.* 4to. Tubingen; Henley, *Phil. Trans.* 1776, p. 463; Cavendish, *Phil. Trans.* 1776; Achard, on Hatching Eggs, *Mém. Acad. Berol.* 1778; Troostwyck and Krayenhoff, *de l' Application de l'Electricité,* 4to. Amst. 1788; Giovani Viventrio, *Istoria dell' Ellettricita Medica Napoli,* 4to. 1784; Bertholon, *de l'Electricité du Corps Humain,* 2 vols. 8vo.; Chappe and Mauduyt, *Jour. de Phys.* xl. p. 62—241; Volta, Gilbert's *Annalen,* vol. xiv. p. 257 and 423; Mauduyt, *Mémoire sur les Differentes Manieres d'Administrer l'Electricité,* Paris, 1784; Chifoteau, *Jour. de Medicine,* Mars. 1784; Nollet, *Recherches,* p. 336; Van Marum, *Phil. Mag.* vol. viii. p. 194, 318; Achard, *Phil. Mag.* vol. iii. p. 51; Abdilgaard, *Tentamina Electrica in Animalibus Instituta Col. Soc. Med. Hafn.* vol. ii. p. 157; Hemmer, *Elektrische versuche mit belegten Thieren, Com. Ac. Theod. Palat.* vol. v. p. 158; Cavallo's *Electricity,* vol. i. p. 87; Carpue's *Medical Electricity,* London, 1803.

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§ IV. *Effects of electricity in the production of chemical composition and decomposition.*

The present section will be found by no means so comprehensive as may at first be supposed, for although it is unquestionable that electricity is capable of exerting a very decided influence upon the ultimate molecules of matter, yet this effect is to be traced principally under that modification which the galvanic battery produces. The oxidation of metals by powerful electric explosions, seems to be effected in a great measure by the elevation of temperature, and not immediately by a pure electrical agency. The case at least with respect to metallic wires which are fused, volatilized, and sometimes oxidated by the electric discharge stands thus. It is obvious that the metal becomes intensely heated, and from this cause alone we know that it would be enabled to combine with the oxygen of the atmosphere, and pass to the state of an oxide. Some peculiar predisposing or determining agency may also very possibly accompany the electricity; but as this can only be inferred, and the former source of oxidation is known and apparent, we hold it to be more correct to consider the oxidation thus produced an effect of heat, and therefore to reserve the recorded experiments on this subject for the sixth section of this chapter.

Dr. ley.

(166.) Dr. Priestley appears to have been almost the first person who attempted to apply the power of electricity to chemical purposes. In his experiments upon air he states that Warltire had already fired a mixture of atmospheric air and hydrogen gas by means of the electric spark, and that upon the disappearance of part of the gases a dewy moisture was found adhering to the inner surface of the glass vessel. Priestley contrived to pass a current of electrical sparks from a brass wire through a small quantity of water in a glass tube. The water was coloured blue by litmus, and after sparks had thus passed for two or three minutes, the blue coloured liquor gradually became red, especially at that part which the sparks entered, and the air confined in the tube suffered some diminution. Hence it appeared an acid had been formed, and it seemed probable, that in some way or other this had taken place at the expense of the air confined in the tube. To examine this point, the tube was placed under the receiver of an air pump, and by gradually exhausting the air, that portion enclosed within the tube, expanded and forced out the changed liquor. By readmitting the air, a fresh portion of coloured liquor was introduced while the confined air remained the same as before, and resumed the space which it had occupied, after the passage of the electrical current. After this, the current of electricity was not able any more to change the colour, nor to produce a diminution in the volume of enclosed air.

Priestley also found that an inflammable gas was evolved, by passing a current of electric sparks through any kind of oil. The oils operated upon were olive oil, turpentine, and the essential oil of mint. The same effect was obtained from ether.

When the spark was passed through ammoniacal gas, the volume of the gas was increased, so that two hundred shocks passed through a given quantity would sometimes produce an expansion of one-fourth. By the subsequent admission of water the original quantity operated upon was absorbed; and the remaining gas, equivalent to the expansion produced by the electricity, was found to be highly inflammable.

Slight shocks were passed for about an hour through an inch of carbonic acid gas, confined in a glass tube $\frac{1}{12}$th of an inch in diameter; and upon the admission of water, one-fourth part only was absorbed.

By operating in a similar manner upon carburetted hydrogen, charcoal in a pulverulent form was deposited upon the inside of the tube.

In one instance Dr. Priestley had passed a succession of electric sparks from a conductor of moderate size, for the space of five minutes, through some carburetted hydrogen gas, without producing any apparent effect of decomposition. But upon passing through it only two shocks of a jar, each of which might be produced in less than a quarter of a minute with the same machine in the same state, the inside of the tube was entirely covered with the black carbonaceous matter. In these experiments it appeared that if the quantity of the gas operated upon were great, no shock, however powerful, would produce the chemical decomposition.

Caven-

(167.) Mr. Cavendish's paper in the *Phil. Trans.* for 1784, will afford the next series of investigations upon these points. A portion of air through which he intended to transmit a succession of sparks was confined in a glass tube A, fig. 87, bent, filled with quicksilver, and immersed in two vessels of the same fluid. The air to be electrified was introduced by means of a piece of glass tube A B C, fig. 88. In using this very ingenious piece of apparatus, the tube A B C is first filled with mercury, and then introduced as in fig. 88, with its bent end uppermost into the vessel which contains the gas, standing in the pneumatic trough. Throughout this part of the process the orifice at C is stopped by a finger, by the subsequent removal of which, some mercury will descend through C, and an equal volume of the gas will enter at the end A. When the proper quantity of gas has been admitted to the tube A B C, it is withdrawn and reversed, so that the end C is placed uppermost, which is to remain carefully closed. The end A, which is made to fit into the end of the tube in fig. 87, is then introduced beneath the mercury in either of the glasses, and by withdrawing the finger from the upper end C of the transferring tube, the mercury descends, and the gas is forced into the tube A, fig. 87. It is necessary that the transferring tube A B C should have only an exceedingly small orifice; and in fact, that employed by Mr. Cavendish was part of a thermometer stem. By means of the same tube a given quantity of soap lees or any other liquor might be introduced within the tube A.

In one instance where it was necessary to introduce several successive portions of air during the same experiment, he gave to his apparatus the form represented in fig. 89, consisting of a tube of small bore A B, a bulb C, and a tube D E of larger bore than the former one. This instrument was first filled with quicksilver, and then the bulb C and the tube A B were filled with the gas, by introducing the end A under the inverted jar upon the shelf of the pneumatic trough, and then drawing out the mercury from the leg D E by a syphon. Being thus furnished with air the instrument is weighed, the aperture at A being closed during this part of the process. The end A of fig. 89 is then fitted into the end of the tube A in fig. 87, and remains there during the experiment. As often as it is necessary to force air out of this apparatus into the tube, a wooden cylinder fitting with some accuracy is thrust down the tube E D, occasionally pouring more mercury in at E to supply the place of that which is forced into the bulb C. Upon completing the experiment the instrument is again weighed. The gain of weight is due to the mercury introduced, and hence the volume of mercury introduced may be calculated, and is equal to the volume of air which has been transferred to the tube A, in fig. 87. The diameter of the bore of the tube A, fig. 87, was usually about $\frac{1}{10}$th of an inch, and the column of air occupying the bend of the tube was from $\frac{1}{2}$ to $\frac{3}{4}$ths of an inch.

In order to pass an electric spark through this tube, it was found advisable not to make a communication between one end of the tube and a conductor, but to place an insulated ball at such a distance from the conductor as to receive a spark from it, and to make a communication between that ball and the mercury in one of the glasses, while the mercury in the other glass communicated freely with the ground.

The passage of the spark through common air in contact with water coloured by litmus, produced a red tint in the coloured liquor as in Priestley's experiments. By confining lime water in the tube instead of litmus, and by continuing the spark until no further diminution was produced in the included air, no cloudiness was perceptible in the lime water, and the diminution of volume amounting to one-third of the original bulk, was more than could have taken place from the effect of deoxidation alone, which would have only diminished the volume by about one-fifth.

By a repetition of this experiment with some impure oxygen gas, a very considerable diminution was produced, but no cloudiness in the lime water, neither could any cloud be perceived upon adding to it a little carbonic acid gas; but on adding a little caustic ammonia a brown precipitate was apparent.

From these experiments it is clear, that the lime water was saturated *by some acid* formed in the process, for the addition of carbonic acid produced at first no precipitation of carbonate of lime; and yet, when by the addition of ammonia, the free acids were saturated, the carbonate of lime was precipitated. The brown colour of the precipitate is supposed to have arisen from some contamination of mercury obtained during the process.

Having confined in the tube some of the same impure oxygen in contact with soap lees, the diminution proceeded rather faster than when lime water had been present; thus it appeared that the greater strength of the alkaline lixivium rendered it more proper than lime water for absorbing and examining the acid produced. Mr. Cavendish then ascertained, that when pure oxygen was employed no absorption was effected, neither was there any when pure azote was enclosed in the tube; but that when five parts by volume of pure oxygen were mixed with three of common air, an absorption almost total took place. Considering common air to contain about one part of oxygen and four parts of azotic gas, it follows that the mixture of five parts of oxygen gas and three of common air was equivalent to seven parts of oxygen gas and three of azotic gas.

Having proceeded thus far, Mr. Cavendish supplied the interior of the tube with a small quantity of the alkaline lee, and then introduced some of the gas mixed in the proportion last mentioned. By a current of sparks diminution of the air kept taking place, and fresh gas was admitted when necessary. At length no further diminution seemed to be produced, and then a little pure oxygen gas, and afterwards a small quantity of common air were added, in order to try whether the cessation of absorption depended upon any failure in the due proportions of the two elements. This not appearing to be the case, the alkaline lixivium was separated from the mercury, and proved to have become perfectly neutral by producing no change in the colour of litmus. By evaporation to dryness a salt was obtained which had the properties of nitre.

Mr. Cavendish subsequently repeated this experiment on a much more extensive scale, and proved incontestably, that the alkaline lixivium was converted into a solution of nitre, that, therefore, nitric acid had been formed during the process, and hence that nitric acid is composed of the oxygen and azotic gases.

Van Marum, &c.

(168.) In the order of time it will be necessary for us next to advert to the experiments of Van Marum, Van Troostwyck, &c. made with the great Teylerian machine at Haerlem. For observing the effect produced by transmitting the electric spark through different gases, a cylindrical glass receiver was employed, 5 inches in length and $1\frac{1}{4}$ in diameter. This receiver was inverted, and a ball and wire were affixed by passing the wire through a hole made in the bottom. By this contrivance a quantity of any gas could be confined over water or mercury; and by bringing the ball near to the prime conductor of the machine a spark would be received, which must escape by passing from the end of the wire within the receiver, through the confined gas, to the mercury or water over which the vessel is supposed to stand. With this instrument it appeared, that oxygen gas obtained from red precipitate underwent a diminution equivalent to $\frac{1}{70}$th its original volume, and that the properties of the quantity remaining were not altered. On pouring out this air, the peculiar smell which electricity frequently elicits was very perceptible.

Nitrous gas was diminished to less than half its original volume, and being then mixed with atmospheric air, no red fumes appeared, neither was there any condensation. Its usual smell was lost, and it would not support combustion. The surface of the mercury was covered with a sort of powder, containing a new combination formed from that metal.

Hydrogen obtained from the action of dilute sulphuric acid upon iron, underwent no diminution, but communicated a slight redness to tincture of turnsol. This probably arose from a slight degree of impurity from admixture of common air with the hydrogen.

Olefiant gas obtained from spirit of wine and sulphuric acid, increased to about three times its original volume, and lost in some degree its inflammability.

Sulphurous acid gas obtained from sulphuric acid and charcoal was diminished a little, and black spots were formed on the inside of the glass receiver. Afterwards it was observed that only $\frac{1}{8}$th of the electrified elastic fluid was absorbed by water. It extinguished a candle and had very little smell.

Muriatic acid gas seemed in a great measure to oppose the passage of the electric fluid, since the sparks would not pass through a greater length than $2\frac{1}{4}$ inches of this air. Considerable diminution was produced, but the remainder was readily absorbed by water.

Carbonic acid gas liberated from chalk by sulphuric acid, was a little increased in volume and rendered less absorbable by water.

Fluoric acid gas was not diminished, nor did it undergo any sensible alteration.

Gaseous ammonia was at first almost doubled in bulk, and then underwent slight diminution. It became unabsorbable by water, and by the contact of flame it exploded, like a mixture of inflammable air with a good deal of common air.

Lastly, common air was tried, and it was found to give a slight redness to the tincture of turnsol, becoming at the same time sensibly deoxigenated. The experiment was repeated thrice at different times, and was examined each time after the electrization, by the admixture of nitrous air in Fontana's eudiometer, and compared with the same air not electrified, the latter always suffering the greatest diminution. In the first experiment the diminutions were $\frac{145}{500}$ and $\frac{175}{500}$; in the second $\frac{159}{500}$ and $\frac{194}{500}$; and in the last $\frac{149}{500}$ and $\frac{178}{500}$. (Cavallo, vol. i. p. 282.)

In attempting to repeat Mr. Cavendish's experiment on the production of nitric acid, by electrifying a mixture of the azotic and oxygen gases, Van Marum made use of a glass tube $\frac{1}{4}$th of an inch in diameter; into the closed end of which an iron wire $\frac{1}{130}$th of an inch in diameter was affixed; this tube having been filled with mercury was inverted over that fluid and placed in a vertical position, after which the air to be operated upon was introduced. The oxygen gas was obtained from red oxide of mercury, and carefully purified by alkali from any acid vapour with which it might be contaminated. With five parts of this gas three of common air were mixed, and a quantity introduced which occupied three inches in length of the tube. To this there was added $\frac{5}{12}$ths of an inch of alkaline lixivium, such as employed by Mr. Cavendish. By a current of electric sparks transmitted through the tube for fifteen minutes, two inches of the gaseous mixture were absorbed by the lixivium. By further addition of the mixed gas, and continuation of the process, $8\frac{3}{4}$ inches of air were absorbed. The lixivium proved to have become impregnated with nitric acid, but not to saturation. With the same lixivium the experiment was resumed, and 14 inches more of air were absorbed; and the rate of diminution did not seem to decrease although the lixivium had now absorbed seventy-seven times its own volume of gas, whereas in Mr. Cavendish's experiment only thirty-eight measures of the air had been taken up.

In a similar experiment made with oxygen gas obtained from minium, the alkaline liquor was made to absorb 178 times its own volume of gas without seeming to have approached toward the point of saturation.

Dr. Van Marum then wrote to Mr. Cavendish on the subject, and was informed that the oxygen gas employed had been obtained from "a black powder produced by shaking mercury with lead." On a subsequent application for further information, a misunderstanding arose on the part of Van Marum who supposed that Mr. Cavendish had endeavoured to conceal the process for obtaining this oxygen; and Cavendish to prove that he had made no secret of the matter, published the letter which he had previously sent to Van Marum.

Proceeding with the researches of Van Marum, we learn that oxygen gas obtained from red oxide of mercury, and had been kept a week, underwent a diminution of $\frac{1}{5}$th by the application of electricity for thirty minutes. The surface of the mercury became oxidated, and it would appear that combination took place between the vapour of mercury in the tube and the oxygen; for towards the end of the experiment the glass tube was so coated with oxide as to have ceased to be transparent. By confining some of the same gas over water, and thus acting upon it, a diminution was here also obtained. The cause of this was not satisfactorily investigated, but in all probability it was owing to the absorption of gas by the water.

It does not appear that pure azotic gas electrified alone and then in contact with alkaline lixivium, underwent any permanent alteration.

Nitrous gas confined by lixivium, being electrified during half an hour, lost $\frac{3}{4}$ths of its volume; the lixivium appeared to have absorbed a great quantity of nitric acid; and the gas remaining in the tube did not seem to differ from common azotic gas. Some of the same nitrous gas, confined by lixivium, was, by standing three weeks, diminished to half its volume, and this residuum also proved to be azotic gas.

Hydrogen gas confined by infusion of turnsol, was electrified for ten minutes without producing change of colour in the infusion or diminution in the gas.

Three inches of olefiant gas, by fifteen minutes' application of electricity expanded to ten inches. It had then lost its inflammability, and upon the addition of nitrous gas no diminution ensued.

A column of ammoniacal gas three inches in length expanded to six inches in four minutes, but by a continuation of electricity for ten minutes longer, no further increase took place. Water would no longer absorb this air, which had now become slightly inflammable.

The following singular experiment is also described: "two balloons made of the allantoid membrane of a calf, were filled with hydrogen gas, of which each contained about two cubic feet. To each of these was suspended by a silken thread about eight feet long a weight, just sufficient to keep it stationary at a certain height in the air. The balloons were connected, the one with the positive, the other with the negative conductor, by small wires about 30 feet in length; and being kept nearly 20 feet asunder, were placed as far from the machine as the length of the wires would admit. On being electrified these balloons rose up in the air as high as the wires allowed, then attracted each other, and uniting as it were into one cloud, gently descended."

M. Achard. (169.) M. Achard wishing to ascertain what effect would be produced on air electrified without sparks, filled a Leyden flask with air, (the degree of oxigenation of which he had previously ascertained by an eudiometer,) and electrified it as strongly as possible: he then let it stand a few hours, and examined the air again. Neither contraction nor dilatation had taken place; and the same result was obtained even when he had exposed the jar to abundance of sparks. The quality of the air had not been changed by the mere presence of the electricity.

He then by a careful repetition verified Franklin's experiment, by which it appeared that the quantity of air in a jar was neither increased nor diminished by the introduction of a charge of either positive or negative electricity. The rarefaction of air produced in Kinnersley's air thermometer, (31.) is an expansion solely due to the increase of temperature from the passage of the sparks through a resisting medium.

Synthesis of water. (170.) The experiments of Priestley on the reduction of the metallic oxides by heating them in hydrogen, are frequently supposed to have led to the knowledge of the compound nature of water. In this, however, as in many similar cases, the general progress of science was such, that this important discovery seems almost to have been made in several places about the same time. About the latter end of 1776, Macquer attempted to ascertain whether any carbonaceous matter were produced in the combustion of hydrogen gas, by holding a china saucer over the flame. He found however only some drops of water upon the surface of the saucer. MM. Bucquet and Lavoisier in September 1777, wishing to learn whether carbonic acid could be produced by the combustion of hydrogen, fired five or six pints of this gas in a wide mouthed bottle, at the same instant pouring in two ounces of lime water. There was no carbonic acid, and the process was such that the water produced escaped unnoticed. In 1781, after some attempts made by Mr. Warltire and Dr. Priestley, who fired mixtures of common air and hydrogen in close vessels, and remarked an appearance of dew on the inner surfaces; the complete and satisfactory synthesis of water was performed by Mr. Cavendish, to whom the honour of this discovery is generally and justly ascribed; although it appears that Mr. Watt, who had reasoned upon Priestley's experiments, had arrived at a similar conclusion, which he communicated to Dr. Priestley by letter, dated April 26, 1783. Mr. Cavendish, in 1781, burned 500,000 grain measures of hydrogen, and having collected 135 grains of pure water, ventured upon the bold conclusion, that water was compounded of the two gases, oxygen and hydrogen. The celebrated Lavoisier having had a different object in view, though he made many experiments on these substances, did not arrive at the true composition of water, until he was informed by Sir Charles Blagden of Mr. Cavendish's result, which he immediately verified upon a large scale.

Analysis of water.

The *Journal de Physique* for 1789, contains an account of the discovery of the decomposition of water by electricity, made and communicated by three associated Dutch chemists, Messrs. Paets, Van Troostwyck, and Dieman. They set out by reasoning upon the theories which then agitated the chemical world respecting the constitution of water, and either inadvertently or disingenuously attribute the knowledge of its synthesis to Lavoisier and the French chemists. They proceed to state that "being employed with Mr. Cuthbertson in an investigation of the effects of electric shocks on different substances, they had the curiosity to observe its effect upon water also. For this purpose they filled a tube of $\frac{1}{8}$th of an inch in diameter, and a foot in length, with distilled water. One extremity of the tube was hermetically sealed, and a gold wire was closed in it, which projected an inch and a half within the tube. The other extremity of the tube was immersed in a small glass vessel full of distilled water, and another wire passed through this aperture and went up into the tube so as to be $\frac{5}{8}$ths of an inch distant from the first mentioned wire. In order to transmit the electric shock, so that it should pass through the water contained in the tube, between the extremities of the two wires, the closed end of the tube was placed against a copper ball standing insulated at some distance from the prime conductor of the machine; and a communication was made from the extremity of the wire which stood in the vessel full of water, to the outside of a Leyden jar, having one square foot of coated surface, and whose knob communicated with the prime conductor. The electrical machine employed was a very powerful double plate one, on the Teylerian construction, causing the jar described to discharge itself twenty-five times in fifteen revolutions. By a series of shocks with this apparatus, decomposition was effected, and the upper part of the tube was speedily filled with gas. As soon however as the electrical discharge passed through any portion of this gas, a re-union instantly took place, water was formed, and there remained only a small quantity of air which did not entirely disappear; and upon repeated trials it was found that a fresh discharge passed through this residuum would produce further combination, and thus the volume of gas remaining, though never entirely recombined, become only $\frac{1}{10}$th of that volume originally produced by the decomposition.

These experimentalists concluded, that the gas produced by the electrical discharges, was a mixture of oxygen and hydrogen from decomposed water;

1st, Because no other gas then known would instantly disappear on passing an electric spark through it; and

2dly, That the gases obtained must have been oxygen and hydrogen, from the decomposition of the water, because they were in such proportions that their recombination produced water; the small gaseous residuum being probably a portion of air previously held in a state of mechanical admixture with the water.

They found that liquids which were compounded of other elements beside hydrogen and oxygen, such as sulphuric and nitric acids, afforded gas by the action of electric discharges, but such that it did not again disappear upon passing an electric spark through it; but was condensed by the addition of nitrous gas over water. Hence it would appear that oxygen gas had been evolved by the partial deoxidation of the bases of these acids.

(171.) The experiments last recited, were carefully repeated by Dr. Pearson. He first states that the decomposition of water by electricity may be effected by what he calls the *interrupted* explosion, employed by the Dutch chemists, or by the *uninterrupted* or *complete* explosion.

Dr. son.

For the success of the former process, Dr. Pearson considers it necessary that the machine should be of considerable power, and prefers a plate machine to one made with a cylinder. The jar should have 150 or 160 square inches of coated surface; and the distance between the insulated ball and the prime conductor must always be less than the distance between the extremities of the wires. The distance between the extremities of the upper and under wire, which seemed to answer best with the power already described, was from $\frac{5}{8}$ths to $\frac{7}{8}$ths of an inch. The diameter of the upper wire cannot be too small, and the diameter of the tube should not be more than $\frac{1}{8}$th nor less than $\frac{1}{10}$th of an inch. The apparatus employed by Dr. Pearson for the other process, is described in his memoir on the subject.

On the whole, his experiments led him to conclude that the mere concussion of the electric discharges, appears to extricate not only the air mechanically combined with water, and separable by boiling and the air pump, but also a further portion upon which these two processes have no effect. The quantity of this air differed greatly in several specimens of water operated upon; but in all cases, though varying in purity at different periods of the process, it seemed to consist of a mixture of oxygen and nitrogen, such as is found to constitute our atmosphere.

After this air, which is supposed to exist unchanged in a state of admixture with the water, has been removed by the first application of the discharges, the true decomposition of the water by the separation of its two gaseous elements commences, and the following are the properties of the mixed gas produced. Immediate condensation by the transmission of an electric spark, with the reproduction of water. The addition of some nitrous gas produced an immediate absorption, probably from the formation and solution of nitric acid.

To the quantity remaining after the oxygen had been saturated by nitrous gas, a fresh portion of oxygen was added, and upon passing an electric spark through a quantity of this mixture well dried, immediate condensation with deposition of moisture was produced. Several other ingenious experiments tending to confirm the opinions which these admirable researches had induced, will be found by a reference to the paper from which these leading facts are extracted.

(172.) In all these experiments we have seen, that to effect the decomposition of water, it was necessary to employ a succession of discharges from a coated surface, and that a series of sparks as they had hitherto been applied, was from some cause or other incapable of producing a similar effect.

This anomaly, if such it can be considered, was removed by Dr. Wollaston in the year 1801. This most accurate philosopher, who seems to possess a peculiar power of justly estimating the relative magnitudes of cause and effect, and of compelling their mutual adaptation; together with a skill in all manipulations ractical ctricity.

confessedly not surpassed, and rarely equalled by any, gives the following account of his process:

"It has been thought necessary for the decomposition of water to employ powerful machines and large Leyden jars; but when I considered that the decomposition must depend upon duly proportioning the strength of the charge of electricity to the quantity of water, and that the quantity exposed to its action at the surface of communication depends on the extent of that surface, I hoped that by reducing the surface of communication, the decomposition of water might be effected by smaller machines, and with a less powerful excitation, than have hitherto been used for that purpose: and in this hope I have not been disappointed.

"Having procured a small wire of fine gold, and given it as fine a point as I could, I inserted it into a capillary glass tube; and after heating the tube so as to make it adhere to the point and cover it in every part, I gradually ground it down till, with a pocket lens, I could discern that the point of the gold was exposed.

"The success of this method exceeded my expectations. I coated several wires in the same manner, and found that when sparks from the conductors before-mentioned were made to pass through water, by means of a point so guarded, a spark passing to the distance of $\frac{1}{8}$th of an inch would decompose water, when the point exposed did not exceed $\frac{1}{700}$th of an inch in diameter. With another point, which I estimated at $\frac{1}{1500}$th, a succession of sparks $\frac{1}{30}$th of an inch in length, afforded a current of small bubbles of air.

"I have since found that the same apparatus will decompose water, with a wire $\frac{1}{40}$th of an inch diameter coated in the manner before described, if the spark from the prime conductor passes to the distance of $\frac{2}{10}$ths of an inch of air.

"In order to try how far the strength of the electric spark might be reduced by proportional diminution of the extremity of the wire, I passed a solution of gold through a capillary tube, and by heating the tube expelled the acid. There remained a thin film of gold, lining the inner surface of the tube, which by melting the tube was converted into a very fine thread of gold, through the substance of the glass.

"When the extremity of this thread was made the medium of communication through water, I found that the mere current of electricity would occasion a stream of very small bubbles to rise from the extremity of the gold, although the wire by which it communicated with the positive or negative conductor, was placed in absolute contact with them. Hence it appears that decomposition of water may take place by common electricity, as well as by the electric pile, although no discernible sparks are produced. The appearance of two currents of air may also be imitated, by occasioning the electricity to pass by fine points of communication on both sides of the water; but in fact the resemblance is not complete; for, in every way in which I have tried it, I observed that each wire gave both oxygen and hydrogen gas, instead of their being formed separately, as by the electric pile.

"I am inclined to attribute the difference in this respect, to the greater intensity with which it is necessary to employ common electricity; for, that positive and negative electricity so excited, have each the same chemical power as they are observed to have in the electric pile, may be ascertained by other means." *Phil. Trans.* 1801, p. 432.

Chap. VI.

(173.) Before we finally take leave of gaseous composition and decomposition, we shall introduce the following observations and table from Mr. Singer, with slight numerical corrections, such as the knowledge of the present time may afford.

"In these experiments the gases are usually exposed to the action of electricity in a closed tube with two wires passing through its sides near the closed end: the tube is filled with mercury, and inverted in a vessel of the same fluid, and the gas being then introduced until it presses the mercury below the wires, sparks are passed between them until the required change is produced; with mixtures of inflammable gases and oxygen, the first spark usually produces the change, but with other mixtures it is sometimes necessary to continue the current of sparks for hours.

"When figures are prefixed to the gas or to the result in the following table, they indicate the proportional measures employed or produced. The use of different proportions will frequently occasion a variation in the result:

Mixed Gases.	*Result.*
Atmospheric air and hydrogen	Water and nitrogen.
100 Oxygen and 200 hydrogen	Water.
160 Chlorine, 100 hydrogen	200 muriatic acid gas.
Muriatic acid gas and oxygen	Chlorine, (and water?)
Carbonic oxide and oxygen	Carbonic acid.
Nitrogen and oxygen	Nitric acid.
Sulphurous acid and oxygen	Sulphuric acid.
Phosphuretted hydrogen and oxygen	Water and phosphoric acid.
Sulphuretted hydrogen and oxygen	Water and sulphurous acid.
150 Oxygen and 200 ammonia	Water and 100 nitrogen.
100 Olefiant gas and 284 oxygen	Carbonic acid and water.
100 Olefiant gas and 100 oxygen	Carbonic oxide and hydrogen.
100 Carburetted hydrogen and 100 oxygen	Carbonic oxide and hydrogen.
100 Carburetted hydrogen and 200 oxygen	Carbonic acid (and water?)

Compound Gases.	*Result.*	
Muriatic acid	Hydrogen	Messrs. Henry and Dalton.
Fluoric acid	Hydrogen	
Nitrous gas	Nitric acid and nitrogen.	
Carbonic acid	Carbonic oxide and oxygen.	

Compound Gases.	*Result.*
100 Sulphuretted hydrogen	Sulphur and 100 hydrogen.
100 Phosphuretted hydrogen	Phosphorus and 100 hydrogen.
100 Ammonia	150 Hydrogen and 50 nitrogen.
100 Olefiant gas	Carbon and 200 hydrogen.
100 Carburetted hydrogen	Carbon and 200 hydrogen.

With some of these results we do not feel perfectly satisfied, but the more minute investigation of this point is in the province of the chemist rather than in that of the electrician.

"These various effects produced by the same agency scarcely appear susceptible of any other explanation than that which assumes the action of electricity to be mechanical; and even on this assumption they are not strictly intelligible. The momentary agitation into which the various mediums are thrown by the action of the spark, might be considered as likely to promote a new arrangement of parts; but, admitting this, why are the changes instantaneous in some instances and gradual in others? and by what inversion of principle is the same impulse that unites the particles of bodies, enabled subsequently to separate them? These are questions it would be interesting to resolve; but there appears no clue by which such intricate processes can be at present analyzed. The chemist must therefore be content to avail himself of the practical advantages they afforded to his art, and await the progress of discovery for the developement of their theoretical relations." Singer's *Electricity*, p. 200.

With these remarks of Mr. Singer we are in some degree inclined to coincide, but at the same time we are disposed to attribute these singular processes more to molecular polarity, than to mechanical agency. That some such power exists in connection with electricity, is fully proved by the invariable manner in which all elements during the process of decomposition, appear at one or other of the wires of the voltaic or electrical circuit. Thus in the separation of the gaseous elements of water, the current of oxygen always issues from the wire which affects the electroscope with positive electricity, while hydrogen invariably follows the contrary rule. The same unchangeable tendencies are perceived in all solid and liquid bodies, wherein the motions of the particles can be made apparent to our senses; and it can scarcely be considered too hasty a generalization, to suppose that some such process takes place with regard to the molecules of matter, which from the peculiarity of their physical condition exist in the gaseous state; though these are not the objects of our vision.

With regard to those cases in which electricity manifests a power of disuniting the elements of a compound body; and also, if the same elements in mechanical, but not in chemical combination, be submitted to its influence, of promoting their union; we might easily adduce analogous facts, wherein feeble chemical affinities have their resultant force absolutely reversed by incidental changes in quantity or temperature.

Oxidation and deoxidation.

(174.) The reasons which have induced us to refer the oxidation of metals by the electric discharge to a subsequent section, are already before our readers. The converse property of deoxidation was known to many of the early electricians. Beccaria reduced the oxides of zinc and mercury to the metallic state. The most convenient process to be employed for this purpose, is to place a quantity of the oxide in a glass tube, inserting the conducting wires into a cork at each end of the tube. This apparatus is then to be placed upon the table of the universal discharger, and repeated shocks are to be passed through the column of oxide until its partial or total reduction is effected.

(175.) The increased rapidity with which putrefaction commences and proceeds, in the bodies of animals which have been killed by electricity, has already been noticed in a preceding section of this chapter, (163.) but might with almost equal propriety have been considered in its relation to chemical phenomena. The experiments before adduced were made by M. Achard, to whom we are indebted also for the following examination of another process strictly chemical, under the modification which electricity is capable of producing upon it.

A handful of rye which had been brought to a state of fermentation in order to be distilled, was divided into two portions, one of which was electrified. Five hours after it had undergone this process, the vinous fermentation was over in this portion, but did not cease in that which had not been electrified until eight hours had elapsed. M. Achard repeated the experiment in such a manner as to send a number of strong sparks through a quantity of rye, instead of giving to it a sort of electrical bath; and with the exception of one case only, he invariably found that fermentation was accelerated by electricity.

(176.) For some of the most recent examinations of the chemical effects of the electricity of the machine, we must again be indebted to Dr. Wollaston's paper of 1801. Of the deoxidating power of negative electricity the following is his elegant illustration: "Having a wire of fine silver $\frac{1}{100}$th of an inch in diameter, I coated the middle of it for two or three inches with sealing wax, and by cutting through in the middle of the wax, exposed a section of the wire. The two coated extremities of the wire thus divided, were immersed in a solution of sulphate of copper, placed in an electric circuit between the two conductors; and sparks taken at $\frac{1}{10}$th of an inch distance, were passed by means of them through the solution. After 100 turns of the machine, the wire which communicated with what is called the negative conductor, had a precipitate formed upon its surface, which upon being burnished was evidently copper; but the opposite wire had no such coating. Upon reversing the direction of the current of electricity, the order of the phenomena was of course reversed; the copper being shortly redissolved by assistance of the oxidating power of positive electricity, and a similar precipitate formed upon the opposite wire."

Similar results were obtained from gold wires, and a solution of corrosive sublimate. The machine employed was a cylinder of seven inches diameter, having a conductor on each side 16 inches long and 3½ inches diameter, each furnished with a sliding electrometer to regulate the strength of the spark received from them.

Having brought forward this instance of deoxidation ctical ctricity. by negative electricity, Dr. Wollaston shows by the following experiment upon vegetable colour, the oxidating power of positive electricity.

"A card being coloured with a strong infusion of litmus, I passed a current of electric sparks along it, by means of two fine gold points, touching it at the distance of an inch from each other. The effect as in other cases depending on the smallness of the quantity of water, was most discernible when the card was nearly dry. In this state, a very few turns of the machine were sufficient to occasion a redness at the positive wire, very manifest to the naked eye. The negative wire being afterwards placed upon the same spot, soon restored it to its original blue colour.'

Cavendish, *Phil. Trans.* 1784, 1785, 1788; Van Marum, *Experiments of* 1785, 1787, Nicholson's *Jour.* vol. ii.; Troostwyck, &c. *Jour. de Phys.* 1789, or Cavallo's *Electricity*, vol. iii. p. 168; Van Marum, *Experiments of* 1795, Nicholson's *Jour.* vol. viii.; Pearson, *Phil. Trans.* 1797; Saussure, *Jour. de Phys.* 1802; Wollaston, *Phil. Trans.* 1801; Achard, Nicholson's *Journal*, vol. iii.; Cuthbertson, Nicholson's *Journal*, 4to. vol. v. p. 136, or *Practical Electricity*, p. 197; Wollaston, *Phil. Trans.* 1801.

§ V. *Effects of electricity in the developement of light from phosphorescent bodies.*

(177.) Of that electrical affection of bodies by which light is developed, we have already given some account in the articles from (29.) to (41.) inclusive, and have there introduced that which we conceive to be the most probable explanation of the production of the light which usually accompanies an electrical discharge in atmospheric air. Were we acquainted with the true and complete solution of this interesting problem, we should be better able to confine the researches we are about to describe, to that specific branch of our subject, to which we suppose them to refer. It is to our ignorance of the real nature of light, that we must attribute the difficulty we experience in attempting to draw a plain line of distinction between the subject of the sections already mentioned, and that which we are now entering upon. If we were to suppose with some, that light is a substantial fluid, united by various forces of attraction to bodies, in which it is capable of assuming a latent state, we might consider the former experiments to relate principally to various methods of exciting its sensible properties in any given substance; and in that case the present series may comprehend the action of some one invariable method by the repeated application of which different effects are produced upon different substances, according to the degrees of power or affinity with which these substances are able to absorb the rays of the luminous principle or fluid.

Why should an electrical spark of the same intensity be of different colours when received from substances dissimilar in their nature? How are some bodies enabled to retain for a time a luminous appearance which they acquire by the passage of an electrical discharge through them, while others do not so? If a flash of light, produced by an electrical discharge in the presence of several substances which form no part of the circuit, communicate to some phosphorescent properties, and to others not; and where light is developed the colours are different upon different bodies; where is the theory of light sufficiently extensive to give a complete explanation of all these phenomena?

(178.) To return from these at present useless speculations, which depend rather upon the nature of light, than upon the manner of electrical action, we propose to give a condensed view of the researches of Mr. Skrimshire, which fall within the peculiar province of this section.

It has been proved by Morgan, that there is no fluid, nor solid body, that may not be rendered luminous by the transmission of an electrical discharge through its substance; and that the difficulty of producing this appearance in all bodies increases as the conducting power of the body decreases. Thus, fluids confined in glass tubes into which metallic wires passed through perforated corks, exhibited this appearance by the transmission of a charge between the extremities of the wires placed at a small distance from each other. In consequence of the conducting power of the metals, it was necessary to reduce the dimensions of the channel of communication very greatly before any luminous effects could be produced; of this we have already mentioned an instance. (37.) In different states of the same body, the ease with which light was developed, increased with every diminution of density; this was proved with the vapour of ether, spirit of wine, and water. The mineral acids, Mr. Morgan considered good conductors; for he found that to obtain a luminous discharge through them, it was necessary to draw a line of the acid upon a plate of glass with a camel's hair brush. For some other interesting results of a similar nature, we can only refer to the paper published by Mr. Morgan. (*Phil. Trans.* 1785.)

Mr. Skrimshire's experiments, to which we have before alluded, were performed by placing the substance to be tried, upon a brass plate fixed horizontally upon the ball of a prime conductor; an attempt was then made to obtain a spark from the substance by means of a common discharger. The body was next placed upon a table or wooden stand, and the shock from a Leyden phial first passed over it, about a quarter, or half an inch above its surface; and then, lastly, the discharge was made to traverse its surface, by resting the points of the discharging rods at an inch or more distant from each other upon the stone to be tried. In all these experiments it was found convenient to keep the eyes closed until the sound of the discharge had been heard. Phosphorescence.

Calcareous bodies

Are all more or less phosphorescent; and the spark passed along the surface of a piece of rhombic spar was reflected so intensely, as to illuminate the whole table with a brilliant white light.

Common chalk was rendered extremely luminous by passing the shock at some distance above it. The fluid, when passed along the surface, left a vivid zigzag track of light which continued several minutes.

Ketton stone. Next to chalk in excellence; by passing the shock along the surface, the stone was shattered, and luminous fragments were dispersed in all directions.

Crystal of sulphate of lime produced a vivid greenish light, continuing a few seconds only.

Fresh crystallized nitrate of lime gave sparks of a flame red colour; but did not permanently retain the light.

Muriate of lime rather more phosphorescent than the nitrate.

All the fluates absorbed the light freely; the dark purple spars afforded no spark; but allowed the electric fluid to pass in a purple stream, accompanied with a whizzing noise, whilst a yellowish flour, and another with a greenish tint, which were phosphorescent by heat, afforded very good sparks.

Canton's phosphorus was rendered more luminous by the electric explosion than any substance hitherto tried.

Phosphate of lime. All bones became luminous by the absorption of electric light; the enamel of the teeth still more so. Ivory, very phosphorescent and easily perforated by a discharge.

Phosphuret of lime gave a minute red spark, and was but slightly phosphorescent upon the discharge being made above it. A very small discharge however, if passed through it, was found sufficient to determine the commencement of its combustion.

The testacea, lithophyta, and all calcareous fossils, imbibed the electric light with facility.

Marbles, lime-stones, stalactites, and spars were phosphorescent; calcined oyster-shells and belemnites beautifully so; and yet quick-lime, fresh from the kiln, ranked among the least phosphorescent of the calcareous genus. Skrimshire, Nicholson's *Jour.* vol. xv. p. 281.

Barytic minerals.

Carbonate of barytes afforded no spark; but became for a short time very luminous by the passage of a shock above it.

Sulphate of barytes gave good sparks, but did not become very luminous by the shock. "It is curious that in these two barytic species the facts turn out exactly the reverse of what takes place in the calcareous genus, in which the carbonates give sparks, though they are but slightly luminous compared with the sulphates, which are brilliantly phosphorescent, but give no spark; whereas in the barytic genus, the carbonates are beautifully luminous, but give no sparks; while the sulphates afford good sparks, but are only slightly phosphorescent."

Sulphuret of barytes became only very slightly luminous.

Magnesian minerals.

Pure and carbonated magnesia were both rendered transiently luminous.

Sulphate of magnesia, very luminous through its whole substance.

Sulphuret of magnesia, luminous, but not more so than the carbonate.

Keffekil of Turkish pipes afforded sparks, but was scarcely luminous, unless the discharge were passed along the surface of the mineral.

Chlorite was rendered luminous by the explosion, and gave singularly coloured sparks.

Steatites, talc, and fibrous amianthus gave sparks, and became slightly luminous by the explosion.

Mica afforded sparks, but did not appear to become luminous by the explosion.

Micaceous schistus gave a ramified and coloured spark. Was scarcely phosphorescent, except in the track of the electric fluid.

Argillaceous genus.

Allum, purple spark, luminous by explosion above the surface; shattered by the shock.

Pipe-clay gave sparks; was luminous by the explosion, but not after burning.

Shales and clays generally gave sparks, and became luminous by the explosion.

Slates: all kinds gave sparks, and absorbed light from the explosion.

Hone-stone gave a spark, and became phosphorescent.

Fuller's-earth: a good bright spark, but very feebly luminous.

Reddle: no spark, but rather more luminous than fuller's earth.

Bole: a ramified spark, but not rendered luminous.

Terra sigillata gives a spark, and becomes luminous by the explosion.

Basalt gives sparks; but a luminous trace is only to be formed by resting the points of the discharger upon its surface.

Burnt brick afforded small purple sparks; became slightly luminous by the explosion, but afforded a bright track of light between the points of the dischargers when rested upon the surface.

Queen's-ware gave a good spark, but was not phosphorescent.

Glazing of pottery containing a metallic oxide: not phosphorescent, but gives a good spark.

Silicious genus.

Rock crystal: phosphoric by the explosion.

Silicious sand, washed and dried, luminous only where the points of the discharger were in contact with it.

Quartz is phosphoric, gives no spark but a purple stream; and after the explosion it affords the same odour as when two pieces are rubbed together.

Flints afford small purple sparks.

Egyptian pebbles, felspars, agates, calcedonies, and jaspers, gave hissing purple sparks, and became luminous by the explosion.

Porphyries and granite gave a hissing purple spark; were also luminous by the shock which passed along the surface, producing a very bright track of light, which in some specimens continued luminous for several minutes.

Pudding-stones: a hissing spark; the pebbles more luminous than the cement.

Mochas gave good sparks from the arborescent part, but only a hissing stream from the clear part of the stone. Skrimshire, Nicholson's *Jour.* vol. xvi. p. 107.

Combustible bodies.

Sulphur: roll brimstone: no spark; flowers of sulphur are not phosphorescent.

Phosphorus: inflames both by spark and shock.

Charcoal: some kinds afford sparks, and are phosphorescent; but other specimens had not this property.

Coke gives a good spark, but is not luminous.

Cannel coal and common coal give beautiful sparks.

Peat, hard and dry, affords a good spark; but is scarcely luminous.

trical tricity. Bitumen, hard, gives no spark; but the electric fluid silently passes over its surface; by the shock it is rendered luminous.

Jet and asphaltum afford the same appearance; but are not luminous by the discharge.

Amber gives no spark, but is phosphorescent, especially the fat variety.

Plumbago gives good sparks, and is not phosphoric.

Metals and their oxides.

Not one of the metals is phosphoric by exposure to the light of an electric explosion, if its surface be clean and bright. Some of their ores and oxides become slightly luminous, while many others have not this property in the smallest degree. In short, throughout all these experiments, not one brilliant appearance of phosphorescence was produced by any metal, ore, or oxide submitted to trial. Skrimshire, Nicholson's *Jour.* vol. xix. p. 153.

Mr. Singer has described a few experiments analogous to those in his *Electricity*, p. 201. In addition to the papers already quoted, the reader may consult Gray, *Phil. Trans.* 1735; Canton's Figures of Sparks, *Phil. Trans.* 1754; Lane, *Phil. Trans.* 1767; Crell, *Jour. de Phys.* 1717; Nicholson, *Phil. Trans.* 1789; Eandi, *Mém. Tur. Acad.* 1790; Juch, *Phil. Mag.* vol. v.; Wale, on the Light of Diamonds, *Phil. Trans.* 1708, p. 69; Doppelmayer, *über das Electrische Licht*, 1749; Fayol, on the Illumination of a Plant, *Mém. Acad. Par.* 1759; Nollet, on the Illumination of Ice, *Mém. Acad. Par.* 1766; Nairne, *Phil. Trans.* 1777, p. 614; Morgan, *Phil. Trans.* 1785, p. 272.

§ VI. *Effects of electricity in the evolution of heat.*

Metals fused. (179.) By transmitting electrical discharges through small strips of metal, Franklin found that the metal frequently underwent fusion. The method he employed, was to confine the metal between two plates of glass firmly tied together; and then to place this apparatus within the circuit of the electrical discharge from a jar or battery. The glass planes are frequently broken, and sometimes the metal seems to undergo oxidation and vitrification, by which it is enabled to combine with the surface of the glass. Thus a piece of gold-leaf was found by Franklin, either from this process, or simply from having become imbedded in the glass, to resist the action of nitro-muriatic acid, with which he attempted to dissolve it. Experiments upon the fusion of metals may be found in the writings of Franklin, Canton, Priestley, and Beccaria; but it is from the labours of more recent electricians that we must draw the few facts which we hold it essential to introduce to our readers.

If the charge from a large jar be passed through a small wire, such a degree of heat is evolved, as to produce the ignition of the wire. In this phenomenon the sudden transit of the electric fluid is the primary cause; but of the specific mode by which such an effect is produced, we are at present entirely ignorant. If that which we term electricity be in reality a substantial fluid, it would be consistent with observed analogies, that when a considerable mass of this eminently expansible fluid is forced through a very small channel, and thereby greatly condensed, heat and light should be evolved. The immense velocity of the motions of electricity, will also account for its possessing a very considerable momentum, even should its specific density as a fluid be exceedingly small; and on this supposition it may, in its passage, produce all the effects of violent impact upon the material particles of the substances through which it passes. Should it not possess any of the characteristics of material substance, and be only a property or affection of matter; still, it is obvious from its expansion and other effects, that it acts upon the particles of all matter, in the same way that tangible substance would do; and therefore the heat which it produces, may be supposed to arise, in part at least, from the mechanical compression undergone by that body in which the heat is developed.

We have already remarked, that by the passage of a strong shock, longitudinally through a metallic wire, the length of the wire is diminished, and its diameter proportionably increased; but if the shock be passed through a similar wire, having a weight suspended by it, so as to produce a considerable degree of tension, the length of the wire becomes increased. This fact, we conceive, will admit of an easy explanation, on the supposition that the temporary increase of heat brings with it a corresponding increase in the freedom of motion among the metallic particles, though it may not amount to fluidity; thus, for a short time, the force of tension exceeds the force of absolute tenacity, and the wire is lengthened.

(180.) Some experiments of Dr. Van Marum were made with a view to ascertain the circumstances under which heat was communicated to bodies by electricity, and the sparks were transmitted through imperfect conductors, in order to increase their energy. For this purpose a wooden rod, one inch in thickness and eleven inches in length, was placed between the ball of the conductor, and the conducting wire. A rod of red fir, after having been electrified for three or four minutes, gave sensible signs of heat; and a thermometer sunk into a hole made in the wood, rose in three minutes from 61 to 88 degrees, and in five minutes to 112 degrees. As the sparks, however, often penetrated under the surface of the rod, it at length split at the end, and continually threw out rays sideways, so as to imitate the effects of lightning.

(181.) A very copious selection of experiments upon the fusion and ignition of metallic wires by electrical discharges, might be made from the papers of Mr. Brooke, Baron Keinmayer, Van Marum, Cuthbertson, and Mr. Singer. For this however space cannot now be afforded, and therefore we must content ourselves with abridging the general observations of this last author upon this subject.

"When a powerful electric charge is passed through a slender iron wire, the wire is ignited or dispersed in red hot balls. Very large batteries were formerly considered essential to the production of this effect; but if the wire be sufficiently thin, a single jar, exposing a coated surface of about 190 square inches will suffice. The finest flatted steel wire sold at the watchmakers tool shops, by the name of watch pendulum wire, answers exceedingly well. Cuthbertson's balance electrometer should be employed to regulate the charge; the circuit from the inner to the outer surface of the jar should be short as possible; and the wire intended to be melted placed in a straight line, and confined at the ends by small forceps."

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Exp. "The inside of the Leyden jar, and the bent arm of the electrometer, being connected with the positive conductor of an electrical machine, and two inches of watch pendulum wire placed by means of the forceps, between the lower insulated ball of the electrometer and the coating of the jar, the slider is to be set on the graduated arm of the electrometer to 15 grains. The machine is then to be put in motion, and when the intensity of the charge exceeds the resistance of 15 grains, the beam of the electrometer will descend, and the charge passing through the two inches of wire will render it red hot, and melt it into balls." (Cuthbertson, p. 178.)

Exp. "If the jar has not a paper ring, it must now be breathed into, and eight inches of pendulum wire being placed in the circuit, the slider of the electrometer is to be set at 30 grains, and the turning of the machine resumed. When the charge is sufficiently intense, the beam of the electrometer will descend, and the charge passing through the eight inches of wire, will melt it with the same appearances as the two inches in the last experiment." (Cuthbertson.)

Exp. "Arrange eight inches of wire in the circuit, as in the last experiment; but instead of one jar charged to 30 grains, employ two jars charged to 15 grains. The wire will be melted precisely in the same manner; so that the effect is *equally* increased by *doubling* the *extent* of coated surface, or the *height* to which it is charged." (Cuthbertson.)

"From numerous experiments of this kind, it has been concluded by Mr. Brooke and by Mr. Cuthbertson, that the action of electricity on wires, increases in the ratio of the square of the increased power; since *two* jars, charged to any given degree, will melt four times the length of wire that is fused by *one jar;* and this will be again *quadrupled* by *doubling* the height of the charge." Van Marum had arrived at a different conclusion; for his experiments led him to suppose, that the lengths of wire found by different numbers of jars, varied directly as the extent of coated surface. Mr. Singer, however, contends for the accuracy of Cuthbertson's law; but he reminds us of the caution necessary to be employed in estimating the variations in the powers of different jars, having the same superficial extent of coated surface, if the thicknesses of the jars be unequal. The same author mentions a very large jar in his possession, which, "from the extent of its surface, ought to fuse three feet of wire with a charge of 30 grains; but from its limited electrical capacity, in consequence of extreme thickness, it will melt only 18 inches; and this is correspondent to the conclusion drawn by Mr. Cavendish, that the quantities of electricity required to charge different coated jars of the same extent, will be in the inverse proportion of their thickness." Singer, p. 179.

"The effects of gradually increasing the power of the charge, when wires of the same length and diameter are employed, are very remarkable. If the wire be iron or steel, its colour is first changed to yellow, then (by an increased charge) blue, by a further increase it becomes red hot, then red hot and infused into balls; if we continue to increase the charge, it becomes red hot, and drops into balls, then disperses in a shower of globules, and, lastly, disappears with a bright flash, producing an apparent smoke, which, if collected, is a very fine powder, weighing more than the metal employed, and consisting of it and a portion of the oxygen of the atmosphere with which it has combined."

Van Marum found that in discharging 225 square feet of coated surface through 50 feet of iron wire, $\frac{1}{140}$th of an inch in diameter, a complete restoration of electrical equilibrium was not effected at once; and that the residuum in the battery, was capable of melting two feet of the same wire. He has given a statement of the lengths of wires of different diameters, and of different metals, which his powerful machine enabled him to fuse upon a splendid scale. Unfortunately, however, these experiments do not present us with any very definitive results, for the fusing points of the metals may be more accurately estimated by other processes; and, supposing such a point in the scale of temperature already known for each metal, the variations in conducting power with regard to heat, and the interference of atmospheric changes, leave us no reasonable hope that the electrical conducting powers of the metals can be ascertained by this process, although it is probable that on the degree of perfection or imperfection of this property, the evolution of heat is dependent.

On the whole, however, he found that with wires of different metals, all drawn to the $\frac{1}{32}$th of an inch, and with an equal electrical charge, he could fuse of lead wire 120 inches; of tin wire, the same quantity; of iron wire, 5 inches; of gold wire, $3\frac{1}{2}$ inches; and of silver or brass, or copper only, $\frac{1}{4}$th of an inch. From these experiments he infers that lead is the worst, and copper the best metal for the formation of conductors for defending buildings from lightning.

(182.) Mr. Cavallo examined the fusion of grains of native platinum by electricity; the metallic grains were placed in a groove $\frac{1}{10}$th of an inch deep, made upon the surface of a cake of wax. Through a line of metallic particles thus arranged, it was easy to discharge a battery, and the grains of metal were by these means partially, but evidently fused, so that sometimes two or more of them adhered together.

As the grains of metal, when promiscuously taken, were sometimes large, and at other times small; one might have expected, that the small grains would have been fused easier than the large ones; but this was by no means always the case; some of the small grains were so refractory as not to show any marks of fusion when examined with the microscope, even after having suffered several electric shocks. On the other hand, some of the large grains were frequently agglutinated together by a moderate shock. Upon the whole, it seems that the whiter grains are fused more easily than those of a dark grey colour. Cavallo, iii. p. 252.

These differences in the fusibility of the grains of crude platinum, are strong proofs of the accuracy of Mr. Cavallo's observations; for it will be obvious to every mineralogist, that the more infusible particles were probably the substance which Dr. Wollaston separated by their appearance, and proved to consist of the alloy of iridium and osmium. Cavallo found that the impure parts of the platinum ore, which were contaminated by particles of gold and iron, were much more easy of fusion; and that filings of pure platinum were more easily melted by this process than the crude grains were. He also remarks, "that the degree of fusibility of different metallic substances, when exposed to the action of electric shocks, is by no means the same as takes place in chemical furnaces; which shows that the electric fluid is not the same thing as the element of fire; the effects, in general, seeming to be proportionate to the degree of resistance which it meets with in its passage; but with respect to metals, the degree of fusibility which they show in this way, seems to be in the compound proportion of that resistance which each particular metal offers to the passage of the electric fluid, and of its natural degree of fusibility, when exposed to a common fire."

(183.) We now proceed to give some account of those experiments in which the heating power of the electrical discharge has been employed to assist the combination of metallic bodies with oxygen. Of these the earliest, which it may be interesting to examine, were made by Mr. Cuthbertson. This electrician seems to consider that Van Marum and himself were the first to suppose that the oxidation of metals could be produced by electricity; there is, however, much to that purpose in the treatise of Beccaria, *dell' Elettricismo Artificiale*. Cuthbertson states that, in 1787, he and Van Marum had produced flocculi from different metals, by subjecting them to strong electrical discharges; but that several accidents happened to their apparatus, which was so frequently broken as to deter Van Marum (much to the dissatisfaction of Cuthbertson) from all further prosecution of these researches. In 1792, 1793, Mr. Cuthbertson undertook two courses of experiments at Amsterdam upon this subject, which ended, as he says, "with little more information than we before possessed." Subsequently, however, he returned to the same pursuit in London, and with better success. The instrument employed is represented in fig. 90, and may be thus briefly described. A glass cylinder, eight inches long and two and a half in diameter, is closed at its two ends by brass caps. The lower cap is supported by an artificial brass cock, and bears upon its inner surface a small reel. Upon this reel there is wound a fine packthread, along which a metallic wire runs evenly, and is tied to the packthread at every fourth inch. A brass tube about three inches long is screwed into the upper cap, and filled with lard and tow, so that the packthread and wire may be drawn through it from the reel, while the cylinder remains perfectly air-tight. The wire by this means may be submitted to the electric discharge in successive lengths, without opening the cylinder. A is a gage formed of a graduated glass tube, about 10 inches long, which may be screwed upon the end of the stopcock; and by immersing the lower end of the tube in mercury, and opening the stopcock, the air absorbed by any number of discharges is easily ascertained.

After an explosion made in common air, it is found by examination, that some portion of the oxygen has been abstracted; and if the fusion of the wire be effected, having the cylinder filled with hydrogen or nitrogen, no absorption is produced, neither is there any oxidation of the metal.

The following is a synoptic view of the results obtained by Mr. Cuthbertson, upon a length of 10 inches of different metallic wires, with a battery of fifteen jars, containing about 17 feet of coated surface. The second column contains the diameter of each wire in parts of an inch; the third, the intensity of the charge in grains upon Cuthbertson's electrometer; and the last, the colour of the resulting oxide.

		grs.	
Lead wire	$\frac{1}{90}$	20	light grey.
Tin wire	$\frac{1}{80}$	30	nearly white.
Zinc wire	$\frac{1}{95}$	45	nearly white.
Iron wire	$\frac{1}{150}$	35	reddish brown.
Copper wire	$\frac{1}{150}$	35	purple brown.
Platinum wire ..	$\frac{1}{150}$	35	black.
Silver wire......	$\frac{1}{150}$	40	black.
Gold wire	$\frac{1}{150}$	40	brownish purple.

"These experiments may be varied, by exploding the wires when stretched parallel to and at about $\frac{1}{8}$th of an inch distant from the surface of a sheet of paper or glass; in either case a very beautiful figure is impressed, and on glass a part of the metal in an unoxidated state appears immediately under the wire; whilst the oxidated portion produces a figure of some width, by which it is encompassed. The colours of the oxides produced in this way, differ from those obtained in receivers, many colours being, in some instances, procured from one metal."

A great variety of results may be seen in Mr. Cuthbertson's work, p. 197; but as these charges were so high as to risk the fracture of the battery, Mr. Singer used in his experiments finer wires, and of shorter length, with a more moderate charge. The following is a tabular view of his results; the length of wire exploded in each case being five inches.

		grs.	
Gold wire......	$\frac{1}{130}$	18	purple and brown.
Silver wire	$\frac{1}{160}$	18	grey, brown, and green.
Platinum wire..	$\frac{1}{180}$	13	grey and light brown.
Copper wire ..	$\frac{1}{160}$	12	light brown.
Tin wire	$\frac{1}{180}$	11	yellow and grey.
Zinc wire	$\frac{1}{180}$	17	dark brown.
Lead wire	$\frac{1}{180}$	10	brown and blue grey.
Brass wire	$\frac{1}{180}$	12	purple and brown.

Singer's *Electricity*, p. 186.

It must be obvious to any one acquainted with the chemical properties of the metallic bodies, that many of these are only imperfect instances of oxidation; and that in all cases there is probably an admixture of metallic particles and true oxide, which, on analysis, would be found to differ in proportion at each successive trial.

Beccaria's *Treatise on Artificial Electricity*, Lond. 1786, p. 598; Brooke's *New Experiments in Electricity*, 4to.; Keinmayer, *Jour. de Phys.* vol. xxxiii. p. 101; Van Marum, *Première Continuation des Expériences faites par le moyen de la Machine Electrique Teylerienne*; Cavallo's *Treatise*, vol. iii. p. 250; Cuthbertson's *Practical Electricity*, p. 197; Singer's *Electricity*, p. 174; Winkler, *Phil. Trans.* 1745, p. 772; Miles, *Phil. Trans.* 1745, p. 290; Kinnersley, *Phil. Trans.* 1763, p. 84; Ingenhouz, *Phil. Trans.* 1778, p. 1023; Berthollet, Nicholson's *Jour.* viii. p. 80.

§ VII. *Effects of electricity upon magnetic bodies.*

(184.) The effects to which this section will be limited, are those only which are developed by the action of the common electrical machine. The discovery of Professor Oersted has, indeed, established, beyond question, the truth of the long-suspected connection between electricity and magnetism. This distinguished Dane, and those who have pursued the researches to which he pointed out the approach, have proved that in substances of appropriate nature, electricity may always be employed as the source of magnetic excitation. On that branch of electricity, however, which lies within the peculiar province of this article, scarcely any additional information has been obtained. A series of electro-magnetical results has been brought to light, of interest and importance almost unrivalled in the annals of science; but it was from voltaic electricity that these results were obtained, and of these an ample account has already been given under the Magnetical division of these treatises.

In the *Philosophical Transactions* for 1676, is an account of the effect produced upon the magnetic properties of a compass needle by a violent thunder storm. The thirty-ninth volume of the same work contains two accounts of the communication of magnetism to iron by lightning, which took place at Wakefield, in Yorkshire. Other similar descriptions will be referred to at the close of this section. In one of these instances, which took place on board a ship bound from New York to London, four compasses were totally unfitted for service. These, on their arrival, were submitted to the examination of Dr. Gowin Knight, who found that, besides the destruction of magnetism in the needles, several pieces of wire which had been employed in the construction of the cases, had received charges of permanent magnetism.

(185.) Facts such as these could not be overlooked by Dr. Franklin, who, in enumerating the instances of analogous effects produced by lightning and electricity, brings forward the following experiments in confirmation of his surmises of the identity of these two agents.

By transmitting the discharge of four large jars through a common sewing needle, the needle had acquired magnetic properties, and would assume the position of the magnetic meridian, upon being placed so as to float upon the surface of water. If at the time of passing the discharge through it, the needle lay in the plane of the magnetic meridian, that end which then pointed north continued afterwards to assume the same position when freely suspended; and this result underwent no change, whichever way the discharge passed through the needle, whether from the northward to the southward, or the contrary. But if the needle were first placed, so as to point east and west, that end of the needle at which the vitreous electricity entered, would afterwards point to the north.

It appeared also that the degree of magnetic intensity developed in a needle, by the transmission of a given electrical charge, was greater when the needle had been laid pointing north and south, than it was when the needle had been made to point east and west.

The charge of a large jar or battery, passed through a steel wire placed perpendicular to the plane of the horizon, communicates to it permanent magnetism, and the end which was nearest to the earth at the instant of the discharge, afterwards, in traversing, turns to the north. By replacing the wire in its vertical position, but with the ends reversed, and again transmitting the discharge, the polarity will either be absolutely destroyed, or if not, the poles will be reversed. It is found also, that the polarity of a natural loadstone may be destroyed by the transmission of a powerful electrical discharge.

The experiments of Franklin were verified and extended by Beccaria, who found that lightning always communicated magnetic polarity to bodies containing iron, such even as common bricks. Reasoning upon this principle, he was able, by observing the polarity acquired by such substances, to trace the direction in which the electrical discharge had passed through those bodies that had been struck by lightning. This ingenious philosopher made also some theoretical suppositions respecting the constant circulation of electric matter as a cause of magnetism, and an explanation of polarity; which the discoveries of the present day seem not unlikely to confirm.

Mr. Robins described in the *Philosophical Transactions* for 1746, the disturbances produced upon the compass needle, simply by a slight friction upon the outside of the glass; but these effects seem to have been due to electrical attraction only, which, for the time that it lasted, was sufficient to overpower the terrestrial magnetism, and derange the natural position of the needle.

A very elaborate series of experiments by Van Marum served only to confirm the accuracy of Franklin's results, and added little of novelty to this branch of our investigations. He found, however, that when a steel bar was placed in the magnetic equator, no electricity was communicated by passing a discharge through the bar longitudinally; but that if the discharge were passed at right angles to the axis of the bar, a considerable degree of magnetic polarity was developed, and that the end which lay towards the east, afterwards became the north pole of the bar.

These experiments were made with a battery of 135 jars, containing 130 square feet of coated surface. Needles of various sizes were operated upon, and steel bars as much as nine inches in length. It was also found that whenever the charge of the battery was so great, with reference to the steel bar, as to produce ignition, no magnetical effect was developed.

Consult *Phil. Trans.* vol. xi. p. 647; Dod, *Phil. Trans.* vol. xxxix. p. 74; Cookson, *Phil. Trans.* vol. xxxix. p. 75; Waddel and Knight, *Phil. Trans.* vol. xlvi. p. 111—113; Robins, *Phil. Trans.* vol. xliv. p. 242; Bremond, *Phil. Trans.* vol. xli. p. 614; Mountaine, *Phil. Trans.* vol. li. p. 286; Knight, *Phil. Trans.* vol. li. p. 294; Franklin's *Letters*, p. 90; Priestley's *History of Electricity*, p. 178; Beccaria, *Lettere dell' Elettricismo*, p. 252, or Priestley, p. 351; Van Marum, *Jour. de Phys.* 1787; Singer's *Electricity*, p. 204; Cuthbertson's *Practical Electricity*, p. 233.

CHAPTER VII.

On the various sources of electrical excitation, and on the peculiarities attendant upon its developement, from each of thes sources.

(186.) It remains only that in this chapter we should give a more complete statement of those processes by which the electrical properties of bodies may be developed. For example's sake, we have hitherto adhered to friction, the most usual, and the most manageable, agent employed in electrical researches. It is however quite immaterial from what source, or by what process, the electricity is evolved; and all that has been said respecting the electricity of friction is true of that produced by every other method, allowance being made for incidental variations in the state of its intensity. In the following sections will be found a review of all the known methods by which electricity may be obtained; arranged for the most part according to that order in which the facts have been successively added to the sum of human knowledge. Mention has already been made of the existence of ten or eleven such processes, (5.); but upon more mature consideration, several of these appear to be only variations of each other, and will be noticed as such, reducing the total number to seven, which number future researches may probably still further diminish.

The contact of metals, as employed in De Luc's column is not here inserted, being reserved for the Galvanic branch of our subject.

The order of the succeeding sections is as follows:

§ I. Friction.
§ II. Electricity of animals.
§ III. Change of temperature.
§ IV. The atmosphere.
§ V. Evolution of gaseous matter.
§ VI. Separation of solid particles.
§ VII. Pressure.

§ I. *Friction.*

(187.) After that Du Fay had recognised the distinguishing characteristic of the electric fluids as produced from different substances, it became a prevailing error to consider that one electricity or the other was the invariable produce of any given substance, until the researches of Symmer gave a more just description of the phenomenon, and the simultaneous production or evolution of both fluids was under some name or other admitted by all experimentalists.

The following may serve as the briefest possible abstract of the generalization of our knowledge upon the conditions to be observed, and the effects produced in all cases of electricity produced by *friction.*

All substances are capable of excitation by friction. But, to make this apparent, those that are conductors must be affixed to some insulating handle, otherwise the electricity is carried off as fast as it is generated; in which case, as no accumulation can take place, none of the phenomena that depend upon electric tension will be manifest.

The bodies between which the friction takes place, will invariably be found to have acquired the opposite electrical states.

This is true even when the substances are to all appearance precisely similar; for Æpinus found that by rubbing two squares of glass against each other, they became oppositely electrified, but that the different species of electricity belonged sometimes to one, and sometimes to the other.

From the same body, both the electricities may be evolved in succession, by changing the nature of the substance with which it is rubbed. Thus a piece of smooth glass will be vitreously electrified by the friction of a silk handkerchief; but resinously by the back of a living cat. Some metals render sealing-wax vitreous, others resinous.

The state of a body with regard to its polish is also capable of influencing the electricity produced; for if a piece of polished glass be rubbed against a piece of rough glass the former will become vitreously electrified and the latter resinously. Cavallo states, that if a stick of sealing-wax having a smooth surface, be rubbed with an iron chain, resinous electricity is produced; but if the wax have its surface previously scratched, the electricity will be vitreous.

If unequal surfaces of the same substance be submitted to friction against each other, both will become electrified; and, in general, the one wherein the friction is limited to the least extent of surface, becomes resinous. This may be shown by two pieces of riband. Again, the string of a violin becomes resinously, and the hairs of the bow become positively electrified.

The following curious case depends probably upon the colouring matter of the riband, rather than upon any peculiarity of surface; and there is no reason to suppose that light, abstractedly considered, has any influence upon the experiment.

"Lay a white riband upon another riband of the same size and fineness but black: then holding them by one extremity with one hand, draw them swiftly between the first and second finger of the other hand, by which friction they will both be electrified, and on being separated, the black riband will be found negative, and the white positive." (Cavallo.)

(188.) M. de Luc, who published some interesting researches in Nicholson's *Journal* for January 1811, shall, by the selection of a few extracts, be made to explain his own views upon these subjects. "Friction excited between two bodies has no other effect than that of disturbing the natural equilibrium of the electric fluid, which tends always to be produced among all bodies according to its actual (but in a certain extent local) quantity upon them, and in the ambient air. If both the bodies which exercise friction upon each other are good conductors, this disturbance (the equilibrium being constantly restored) is not perceived; but if one has more disposition than the other to attract the electric fluid thus agitated, with the faculty of transmitting it to its remote parts; when the bodies are separated suddenly, or in general before the equilibrium of the fluid can be restored between them, one is found positive, as having acquired a proportional quantity of electric fluid greater than the ambient air, and the other negative, as having lost that quantity; both being sup- De Luc's observations.

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posed to have previously possessed the same electric state as the ambient air.

"The general effect therefore of friction between two bodies is, that one never becomes positive without the other being negative, (or *vice versa*.) This evident proof that all the electric phenomena, which we are as yet able to produce at will, namely by friction, proceed from the disturbance of the equilibrium of only one fluid, will be afforded by the experiments which I shall here relate.

"Mr. Cavallo, in his complete Treatise on Electricity, (third edit. vol. i. p. 21,) has given a table, containing the results of his experiments of this kind, wherein is found, that certain bodies become either positive or negative, according to those by which they are rubbed. This circumstance had already shown that negative and positive were not properties belonging to certain bodies, but only different states produced on the same body by different circumstances, and in particular by the difference of those which exercise friction on it; there remained however to be ascertained what effect in the latter case, was produced on each of the bodies which exercised that friction. This having been one of my objects in these experiments, I kept both bodies between which the friction took place, insulated; at the same time suffering them to communicate with electroscopes. By experiments thus performed, I discovered the general law above expressed; for when any of the bodies, which may be rendered either positive or negative by friction, was brought to one of these states, the body which had exercised it was constantly found in the opposite state: if the former became positive, it had taken some electric fluid from, and if negative it had yielded some electric fluid to the body which had exercised friction upon it. Such are the effects which will be seen in the following experiments."

De Luc then proceeds to describe an electrical machine, so small that it should only equal the effects of a large electrical column, and might be connected with a gold leaf electroscope, without destroying that instrument by the violence of its action. The power of this machine was intended not to exceed that of an electric column containing 600 groups. The cylinder of this minute apparatus was one-fourth of an inch in diameter; and it was necessary that the motion communicated to it should be very slow, or else the excitation became too great for the purposes of comparison. By the friction of brass upon glass, the brass became negative, and the conductor receiving electricity from the glass, showed a positive state of excitation

When the glass cylinder worked against a small flat piece of glass, the latter not being insulated, the conductor became positive. This experiment is analogous to one which had been some time known to electricians, in which, if two pieces of riband of the same kind be rubbed together, the one throughout its whole length, across the other at one place only, the former becomes positive and the latter negative.

By forming the rubber of insulated sealing-wax, a slight charge of positive electricity was developed upon the cylinder; but when the apparatus had been altered, to allow of the sealing-wax repairing its losses by communication with the earth, the electricity evolved, was more copious.

A rubber of caoutchouc was affixed; and with this it was found, that on some days the glass became positive, and the caoutchouc negative, while on other days, the contrary effects took place.

The glass cylinder was next coated with sealing-wax, and made to undergo the friction of a brass rubber. This proved an experiment requiring some delicacy of execution; but at length, the electroscope communicating with the waxed cylinder, diverged with negative, and that which communicated with the brass rubber, with positive electricity. De Luc here remarks upon the error of those who had supposed that those bodies which were conductors were themselves incapable of excitation, showing that it was only necessary that the body, if a conductor, should be insulated, in order that its electric excitation might become apparent. A similar series of results was obtained by the Abbé Haüy, at a subsequent period. The last experiment also shows, that brass becomes positive or negative, according to the body with which it is rubbed.

To the same cylinder coated with wax, a rubber of caoutchouc was applied. The excitation was extremely powerful; but invariably the sealing-wax with which a brass rubber had been negative, now became positive; and the Indian rubber was constantly negative.

A red bead, formed of an elastic gum, produced by the inspissation of some vegetable juice, and worn for necklaces, gave a similar variety of results. With a narrow brass rubber, the bead became negative, and the brass positive.

"Such are the constant phenomena observed at the fountain head of all the electric effects which it is in our power to produce; and they depend on friction, respecting which various systems have been fabricated. Now from the whole tenour of these experiments, it may be laid down as a fundamental truth in terrestrial physics, that friction has no other influence in electric phenomena, than that of disturbing the equilibrium of the electric fluid, in such a manner, that one body by acquiring a certain quantity of it, above what it had before, is rendered positive, and that the other is found negative, as having lost that quantity. It is only when its equilibrium is disturbed that the electric fluid is manifest to us: the electroscope is our first test of this disturbance; but if the bodies, either conductors themselves, or associated with conductors, are of a sufficient size, and the electric difference between them has arrived to a certain degree, it is manifested by a spark darting from one to the other, and the equilibrium is thus restored."

(189.) Having thus permitted M. de Luc to plead his own cause, by which we do not pledge ourselves to unite with him in all his views, we may for the present be allowed to leave these and similar speculations, until further experiments shall have rendered us more competent to the task of reasoning upon the subject. The table originally drawn up by Mr. Cavallo, and subsequently improved by Singer and others, may stand as follows:

Substance rubbed.	Substance rubbing.	Electricity developed in the former.
Back of a live cat	Every substance hitherto tried	vitreous.
Smooth glass	All substances tried; (mercury and the back of a cat excepted)	vitreous.
	The back of a cat; and on some days caoutchouc. (De Luc.)	resinous.
Rough glass	Dry oiled silk, sulphur, metals, alcohol, ether, and all solid and liquid resins, (Libes.)	vitreous.
	Woollen cloth, quills, wood, paper, human hand, and cat's back	resinous.
Tourmaline	Amber, blast of air from bellows	vitreous.
	Diamond, the human hand	resinous.
Hare skin	Metals, silk, loadstone, leather, human hand, paper, baked wood	vitreous.
	Other fine furs	resinous.
White silk	Black silk, metals, and black cloth	vitreous.
	Paper, human hand, hair, weasel's skin	resinous.
Black silk	Sealing-wax	vitreous.
	Hare's, weasel's, and ferret's skin; loadstone, brass, silver, iron, human hand, white silk	resinous
Woollen cloth	Zinc, strongly; silver and bismuth, strongly; copper, lead, oligistic iron ore, sulphate of Quina at 212, (Dumas.)	vitreous.
	Platina, gold, tin, antimony, grey copper, sulphuret of copper, strong; sulphuret of lead, strong; tellurium from Naygag, strong; antimonial silver; sulphuret of silver, strong; nickel, grey cobalt, arsenical cobalt, sulphuret of antimony, sulphuret of iron, crystallized protoxide of iron, (Haüy, *An. du Mus.* No. 17.)	resinous.
Sealing-wax	White wax, rough glass, sulphur, and all metals tried, except iron, steel, plumbago, lead, and bismuth	vitreous.
	Hare's, weasel's, and ferret's skin; human hand, leather, smooth glass, flannel, quills, wood, paper, iron, steel, plumbago, lead, and bismuth	resinous.
Baked wood	Silk, rough glass, paper, sealing-wax, white wax, lead, sulphur, and all metals	vitreous.
	Flannel, smooth glass, quills, hare's skin	resinous.
Sulphur	All metals, except lead	vitreous.
	Lead, and all substances tried	resinous.
Resinous bodies	Resinous bodies having greater extent of surface	vitreous.
	All bodies except resinous ones	resinous.

Cavallo's *Electricity*; Singer's *Electricity*, p. 34; De Luc, Nicholson's *Journal*, vol. xxviii. p. 11; Libes, *Physique*; Biot, *Physique*; Haüy, *An. du Mus.* No. 17.

(190.) It is a question of great interest to ascertain what office the amalgam performs in the developement of electricity, by the common machine. In one of M. de Luc's experiments, he obtained electrical excitation by the friction of brass upon glass, the former becoming negative and the latter positive. Upon this he remarks as follows:

"This experiment shows what is the effect of the metallic amalgam laid on the rubbers of the usual electric machines. The base of those rubbers must be a cushion, in order to yield to the inequalities of the cylinders or plates, while it presses upon them; but the materials of the cushions are not sufficiently conducting to permit the loss which its rubbed part undergoes, of the fluid carried off by the glass, to be soon repaired by the ground; whereas this is effected by the metallic amalgam, from which the glass takes readily some electric fluid, as, in the experiment now mentioned, it takes it from the brass rubber. Metallic plates would produce the same effect on the cylinders and plates of electrical machines, if the former were sufficiently pliable. Nicholson's *Journal*, vol. xxviii. p. 9.

Experiments of Wollaston

(191.) Dr. Wollaston is of opinion, that it is the process of oxidation which principally tends to the developement of electricity in the common machine, and adduces the following experiments in illustration of his views.

By employing an amalgam of silver, or of platinum, which are metals not liable to be oxidated, he could obtain no electricity. An amalgam of tin, on the contrary, afforded a good degree of excitement. Zinc acts still better; but the best amalgam is made with both tin and zinc, a mixture which is more easily oxidated than either metal separately.

As a further trial whether oxidation assists in the production of electricity, a small cylinder with its cushion and conductor, was arranged in a vessel so contrived that the air contained could be changed at pleasure.

After trying the degree of excitement in common air, carbonic acid gas was substituted, and the excitement was instantly destroyed, but immediately returned upon the readmission of atmospheric air. *Phil. Trans.*, 1801.

The object of Dr. Wollaston in the papers containing these experiments, was to bring a distinct proof of the identity of voltaic and ordinary electricity; and therefore he remarks, that the cushion of the machine by oxidation of the amalgam which adheres to it, becomes negative; and in the same manner zinc oxidated by the accumulated power of an electric pile, or simply by the action of an acid, is also negative.

(192.) The friction of liquids against solid bodies is also capable of developing electricity. To prove this, let a cylindrical glass receiver be placed upon the plate of an air pump, the top of this receiver is to be formed of a wooden cup, fitted into the receiver by cement, and holding mercury. Upon the exhaustion of the receiver, the mercury pressed by the external air, filters through the pores of the wood, and falls in the form of a delicate shower, striking against the sides of the glass cylinder. If then a small electroscopic ball suspended by silk be brought near, the cylinder will be found in the excited state. In order that this experiment may succeed well, some care must be used in making the cylinder perfectly dry, so that it may not lose the electricity produced by the friction of the mercury against its surface, which indeed is never considerable.

By this experiment we are enabled to explain a phenomenon observable in barometers well freed from air. When these are suddenly inclined, so that the column of mercury may rapidly fill all the vacant part of the tube; if the experiment be made in the dark, a phosphoric light is instantly developed, similar to that which is produced by a current of electricity in its passage through a vacuum.

Electrical excitation may also be produced by the friction of a gas against a solid body. If a current of atmospheric air be directed against a plate of glass, by means of a pair of bellows, the glass becomes vitreously electrified. (Wilson.)

By sifting powders.

(193.) There is yet another mode of electrical excitation, which has been long viewed as possessing some distinct and peculiar character. We are inclined however to refer it also to this section, and to consider it a species of friction, differing only from the instances before recited, in the mode of its application.

After Mr. Bennet had invented the gold-leaf electrometer in 1786, he found that powdered chalk put into a pair of bellows, and blown upon the cap, communicated to the instrument vitreous electricity, when the cap was about six inches from the pipe of the bellows; but the same stream of powdered chalk electrified it resinously at the distance of three feet. The electricity is also changed from vitreous to resinous, by placing a bunch of fine wire, silk, or feathers, in the aperture of the bellows pipe; and is wholly resinous when blown from a pair of bellows without the pipe, so as to come out in a larger stream. This last experiment did not answer in dry weather so well as in wet. "The vitreous electricity of the chalk thus blown, is actually communicated, because part of the powder sticks to the cap; but the resinous is not communicated, the gold leaves collapsing as soon as the cloud of chalk is dispersed."

A piece of chalk drawn over a brush, or powdered chalk put into the brush, and projected upon the cap, electrifies it resinously, but the electricity is not communicated.

Powdered chalk blown with the mouth or bellows from a metal plate placed upon the cap, gives permanent vitreous excitation. Or, if the chalk is blown from the plate, either insulated or not, so that the powder may pass over the cap, if not too far off, it is also vitreous. Or, if a brush is placed upon the cap, and a piece of chalk drawn over it, when the hand is withdrawn, the leaves gradually diverge with vitreous electricity as the cloud of chalk disperses.

Powdered chalk falling from one plate to another placed upon the instrument, produces resinous electricity.

Other methods of producing electricity, with chalk and other powders were tried; as projecting chalk from a goose wing, chalking the edges of a book, and clapping the book suddenly together; also sifting the powder upon the cap, all which electrified it resinously; but the instrument being placed in a dusty road, and the dust excited with a stick near to it, produced vitreous electricity.

Wheat flour, and red-lead are strongly resinous, in all cases where the chalk is positive. The following powders were like chalk; red and yellow ochre, resin, coal ashes, crocus powder, aurum mosaicum, black-lead, lamp black, powdered quick-lime, umber, lapis calaminaris, Spanish brown, powdered sulphur, flowers of sulphur, iron filings, rust of iron, sand. Resin and chalk, which when separate are alike, changed their effect by admixture; this was often tried in dry weather, but did not succeed in damp; white lead also sometimes produced vitreous, and sometimes resinous electricity, when blown from a plate.

No sensible electricity is produced by blowing pure air, projecting water, by smoke, flame, or explosions of gunpowder. Bennet, *Philosophical Transactions*, 1787, p. 31.

In a communication shortly following the preceding one, Mr. Bennet says, "To the experiments on blowing powders from a pair of bellows, I have to add, that if the powder is blown at about three inches upon a plate which is moistened or oiled, its electricity is contrary to that produced by blowing them upon a dry plate."

(194.) The experiments of Professor Lichtenberg, by projecting powders upon the plate of the electrophorus, seem to have called Mr. Cavallo's attention to this subject. For ascertaining the electricity of powders, he gives the following directions, and at the same time we may conclude from his speaking in these terms, that he considers the electricity to belong to the substances employed, and not to an extraordinary developement arising out of the process.

"Insulate a metal plate upon an electric stand, and connect it with the electroscope; then the powder required to be tried, being held in a spoon, at about six inches above the plate, is to be gradually let fall upon it. In this manner the electricity acquired by the powder being communicated to the metal plate, affects the electroscope; and its quality may be ascertained in the usual manner.

"If the powder be of a conducting nature, like the amalgam of metals, &c., it must be held in some electric substance, such as a glass phial or a plate of wax. Sometimes the spoon may be insulated, in which case, after the experiment, the spoon will be found possessed of an electricity contrary to that of the powder."

In performing these experiments, care is to be taken that the powders, and whatever they are held in, be as free from moisture as possible.

The most complete series of experiments in this tical ricity.

department is to be found in Mr. Singer's work. In these researches two methods were employed.

1. "That of sifting them on the cap of a delicate electrometer through a fine sieve, which was thoroughly cleansed after each operation.

2. "By bringing an insulated copper plate repeatedly in contact with extensive surfaces of them spread on a dry sheet of paper; the copper plate being brought in contact with the condenser after every repetition of the touching, until a sufficient charge was communicated.

"By each process the effects produced increased considerably, when the substances employed were reduced to a fine powder; and it was in this way I succeeded in obtaining very distinct effects from the alkalis, by contact with a copper or a silver plate; an experiment which Sir H. Davy had before attempted with great care but without success. The pure alkalis were broken into small pieces, and being placed in an open phial were exposed for a quarter of an hour to a moderate heat, not sufficient to fuse the alkali, which was then quickly reduced to a powder in a warm and dry mortar; and immediately spread upon a dry sheet of card paper, which for some time will continue to attract moisture from the alkali, as fast as the alkali receives it from the air. The whole operation was performed as rapidly as possible.

"The greater effect produced in all these experiments by an increased division of the powder, renders it highly probable that they are merely varieties of the usual process of excitation.

"The following substances produce negative electricity, when sifted on the cap of an electrometer: copper, iron, zinc, tin, bismuth, antimony, nickel, plumbago, lime, magnesia, barytes, strontia, alumina, silex, brown oxide of copper, white oxide of arsenic, red oxide of lead, litharge, white lead, red oxide of iron, acetate of copper, sulphate of copper, sulphate of soda, phosphate of soda, carbonate of soda, carbonate of ammonia, carbonate of potash, carbonate of lime, muriate of ammonia, common pearl ashes, boracic acid, benzoic acid, oxalic acid, citric acid, tartaric acid, cream of tartar, oxymuriate of potash, pure potash, pure soda, resin, sulphur, sulphuret of lime, starch, orpiment, &c.

"The following substances produce positive electricity when sifted on the cap of an electrometer. Wheat flour, oatmeal, lycopodium, quassia, powdered cardamom, wood charcoal, sulphate of potash, nitrate of potash, acetate of lead, oxide of tin.

"Hence it appears, that there are comparatively but few substances that become positively electrified when sifted through hair, flannel, or muslin. For in experiments made with each of these substances separately, they were found to produce similar effects.

"The following table exhibits the results of experiments of contact with a copper plate. The different substances being arranged in classes under the electricity they really acquire, which is contrary to that of the copper plate. *Positive:* lime, barytes, strontia, magnesia, pure soda, pure potash, common pearl ashes, carbonate of potash, carbonate of soda, tartaric acid. *Negative:* benzoic acid, boracic acid, oxalic acid, citric acid, silex, alumina, carbonate of ammonia, sulphur, resin.

See Bennet, *Philosophical Transactions*, 1786, p. 30; Cavallo, vol. ii. p. 76; Singer, p. 473.

Chap. VII. Cooling of fused substances.

(195.) In deference to the opinions of those philosophers who have made the most recent and the most judicious researches on this subject, MM. Van Marum, Paets, and Troostwyck, we shall include under the present section some short account of the electricity developed during the cooling of fused bodies, although at first sight it may appear improbable that the electrical effects so produced should owe their origin to friction.

The earliest experiments upon this subject were made by Mr. Stephen Grey, and principally upon bodies of a resinous nature. These substances were fused in iron ladles, and so managed as to get out cakes of the form of the ladle, having smooth surfaces. Resin, sulphur, lac, and various combinations of these, form a very considerable list in the detail of Mr. Grey's experiments. After these masses had been taken out of the ladle, and the surface had become hard, they did not exhibit any electricity, until the temperature had fallen about to that of a new laid egg. The electricity then gradually increased; and when the cakes had become cold, the electrical power had increased in a tenfold proportion. In order to preserve these bodies in their excited state, they were wrapped up in flannel, or in worsted stockings, and kept in a dry box.

The only one of these experiments that we are now in the habit of repeating, is that marked by Mr. Grey, No. 19. A cone of sulphur was cast in a tall glass. About two hours after it was taken out of the glass it attracted, and the glass also slightly. Next day the sulphur was taken out of the glass, and then it attracted strongly; but there was now no perceptible attraction in the glass. This experiment ended as any similar one may now do, by the sulphur and the glass both manifesting electrical properties for several weeks, whenever they are separated from each other.

Experiments of a similar kind are related in the respective Treatises of Wilcke of Rostock, and of Æpinus. Mr. Henley was led to return to this subject, by an observation communicated to him from Mr. Sanders, a maker of chocolate, who found that the chocolate became electrical during its cooling in the tin pans in which it had been cast. From some trials made under Mr. Henley's directions, it appeared, that by heating it over again repeatedly, this property of the chocolate gradually disappeared; but that it might at any time be restored by the addition of a small quantity of olive oil.

In 1784 M. Pabst published a short paper upon the same subject; and in 1787 Mr. Liphardt made further experiments; and seems in a great measure to have satisfied himself that friction was the true cause of this phenomenon.

The question was at length very carefully investigated by Van Marum and his associates; and of the numerous memoirs, ancient and modern, that in compiling this article it has been our business to examine, there are few to equal that of the associated chemists produced upon this occasion. The experiments are definite in their object, and ingenious in their contrivance; and want of room alone compels us to abstract only their concluding sentence.

"It is then (as we think) incontestably proved by the experiments we have just related, that the electricity developed whenever we separate an electric substance which has been fused and cooled from the body on which it has been poured, is not produced by that separation, neither is it produced by the fusion or by the cooling; but, that it is caused by the friction which the particles of the electric bodies undergo, when they disperse themselves over the surfaces upon which they are poured. The reason why this electricity does not manifest itself till after the cooled substance is separated from the body upon which it has been poured, is, doubtless, because the electricity which the body receiving the fused mass must acquire, is opposed to the electricity of the melted body itself, and these two opposite electricities so exactly counterbalance each other as to be quite imperceptible."

Consult Grey, *Philosophical Transactions*, 1732, p. 285; Wilcke, *Disputatio Physica experimentalis de Electricitatibus Contrariis*, Rostock, 1757; Æpinus, *Tentamen*, &c. p. 66; Henley, *Philosophical Transactions*, 1777, p. 85; Pabst, *Sch. An.* 1784, p. 119; Liphardt, *Jour. de Phys.* 1787, p. 431; Van Marum, &c. *Jour. de Phys.* 1788, p. 248.

§ II. *Electricity of animals.*

It might be advanced as a conjecture by no means improbable, that some degree and species of electrical excitation is a constant attendant upon animal life. If our instruments were of sufficient delicacy to detect its presence, and examine its nature under all circumstances, we might then hope to be able to trace its beneficial or injurious influence upon the economy of animated beings. In addition to the electricity developed in the human frame, which seems to be entirely independent of volition, and may possibly arise partly from mechanical causes, and partly from those dependent upon chemical or vital action; there is a series of singular phenomena discovered to exist in the animal kingdom, by which some of its inferior orders of beings are enabled to defend themselves from the attacks of their enemies, or to take the prey which is destined for their support. The section now before us will contain a brief examination of these facts in the following order:

1. Electricity of the human body.
2. Electricity of the Raia Torpedo.
3. Electricity of the Gymnotus electricus.
4. Electricity of the Silurus electricus.
5. Electricity of the Trichiurus Indicus.
6. Electricity of the Tetraodon electricus.

1. *Electricity of the human body.*

Of the human body.

(196.) The excitation produced by the friction of articles of dress upon the human body, cannot in all instances be distinguished from that which results from the operation of other and less obvious causes. For this reason, and for greater convenience in referring to the original memoirs, we shall give a short abstract of our information upon these subjects without attempting to separate the one kind of action from the other.

J. J. Hemmer, who published a Memoir upon this subject in the *Transactions of the Electoral Society of Manheim*, has collected the following instances of the electricity of the human frame; and to these more might, if necessary, easily be added.

Virgil mentions a harmless flame which was emitted by the hair of Ascanius.

> *Ecce levis summo de vertice visus Iuli*
> *Fundere lumen apex, tactuque innoxia molli*
> *Lambere flamma comas, et circum tempora pasci.*
> *Nos pavidi trepidare metu, crinemque flagrantem*
> *Excutere, et sanctos restinguere fontibus ignes.*
> *Æn.* lib. ii. v. 582.

More than one ancient author has related that fire streamed from the hair of Servius Tullius, the Roman King, during sleep, when he was about seven years of age. (Dionysius, *Antiq. Rom.* lib. iv.) Pliny says also, *Hominum quoque capita vespertinis horis stellæ magno præsagio circumfulgent.* (*Hist. Nat.* lib. ii. c. 37.)

Cardan mentions a Carmelite monk, whose hair emitted sparks whenever it was stroked backwards. (Lib. viii. *De Rerum variet.* c. xliii.) A woman at Caumont exhibited a phenomenon of the same kind, as her hair, when combed in the dark, always emitted fire. (Scaliger, *Exercit.* 174.) Father Faber, in his *Palladium Chemicum*, speaks of a young woman from whose head sparks of fire always fell when she combed her hair. Franciscus Guidas produced bright flames from his body, when he rubbed his arm with his hand as he lay in bed. (Bartholinus, *De luce Animalium*, Lugd. 1647, p. 121.)

Ezekiel di Castro, a physician of Verona, relates of Cassandra Buri, a lady of the same place, that, as often as she touched her body, even in a slight manner, with a linen cloth, it emitted sparks in great abundance, which could be perceived by every person standing near her, and were attended with a considerable noise. Her maids were often deceived by this phenomenon, and believed that they had through carelessness dropped some coals between the sheets; as she always caused her bed to be warmed in winter, at which time the sparks were most abundant and strongest. (Castro, *De igne Lambente*.)

Fortunius Licetus relates (*De Causis monstrorum*, lib. ii. cap. 28) that Antonio Ciamfi, a bookseller at Pisa, when he pulled off a narrow shirt and a piece of cloth which he wore upon his breast, emitted sparks from his back and arms, with a crackling noise, to the terror of the whole family.

Among us, says Gesner, where heated chambers are usual, it often happens that many persons when they have warmed themselves at a stove, and then pull off their shirt in a cold bedchamber, or move or shake it after it is pulled off, observe crackling flames to burst from it. (*Lib. de Lunariis.*) Bartholinus mentions a like phenomenon of a rope-dancer at Turin. (*De luce Anim.* p. 123.) Scaliger speaks of a white Calabrian horse, which, when combed in the dark, emitted sparks of fire. (*Exercit.* 174.)

Beccaria describes the following circumstance told to him by Vaudania: "For ten or twelve days past, since the cold set in, I wear between two shirts a piece of beaver's skin. Always when I pull off my upper shirt at night, I observe that it adheres in some degree to the piece of skin; and when I draw my shirt from it I see sparks which have a striking resemblance to those of electricity. Scarcely do I begin to pull off the piece of skin, when I find that it adheres, and with still greater force, to the under shirt. On taking it out, I observe when I hold it in the right hand that ctrical tricity.

the frill of my shirt moves up from my body towards it. If I remove the piece of skin to a greater distance, and draw it from the frill, the latter moves again toward my body. If I bring the piece of skin nearer, the shirt moves again towards it. This oscillation of my shirt between my body and the piece of skin continues alternately, till it is gradually lessened and at length ceases."

These numerous instances must bring to recollection the observations of Mr. Symmer, on the electricity of silk stockings which had been worn; but at the same time it must be remarked, that these are in fact all cases of electricity produced upon the human body by friction, although it does not follow that the same kind and degree of friction should produce the same effects upon all persons. It appears to be clearly proved, that there exist certain predisposing causes in some persons which render them more fit subjects for these experiments than others are.

M. de Saussure had published some observations upon the electricity of the human subject, from which he inferred that bodily motion was necessary to the production of his electricity. For this reason, and because he could obtain no excitation when undressed, he concluded that the electricity resulted from the friction of his body against the clothing. He also states, that it is necessary that the clothes should possess the warmth of the body; for when he had on clothes that were cold, he could never obtain the least trace of electricity; neither when the body was in a state of perspiration. The electricity developed was sometimes positive and sometimes negative; but the cause of that variation he was unabled to discover.

M. Hemmer applied for information to De Saussure, who stated that he had made no further experiments, neither was he aware that any had been made by others. His letter is dated June 21, 1787. Upon this M. Hemmer resumed his inquiries; and in order that he might examine the electricity of his own body he insulated himself on a board standing upon glass feet; he then touched for a time (from one second to half a minute) a plate of a condenser, and then applied it to Cavallo's electroscope; and by an excited glass tube examined the electricity produced. These experiments were made "not only upon himself but upon other persons, both male and female, of various ages and different constitutions, when they were in motion, or at rest, dressed and undressed, when tired or in good spirits, hot or cold, fasting or full, sleeping or awake, at different temperatures of the weather and of the apartment."

From Hemmer's long but rather irregular series of experiments it would appear, that electric excitation is a property of all mankind, that it varies not only in different persons, but in the same person at different times; being in many weak, in other strong, in some vitreous, in others resinous. The variations arise from causes which he was unable to trace. In 2422 experiments made upon himself, 1252 showed vitreous electricity, 771 times resinous, and 399 none at all. In 94 experiments upon his maid, the electricity was 19 times vitreous, 33 times resinous, and 42 times 0.

Even during the continuance of an experiment the electricity frequently changes from vitreous to resinous; but on the whole it appeared that in a quiescent state of the body the electricity was most frequently vitreous. Cold seemed to change the natural or vitreous electricity, into the opposite kind, or at least diminished its intensity. Lassitude produces the same effect. This animal electricity is stronger in winter than in summer, and is impeded by perspiration. Bodily motion is not necessary to its developement; neither does it depend upon the motion of respiration; nor can it be attributed to the friction of the clothes, for M. Hemmer says, "my experiments leave no doubt upon this subject; as I found the electricity on my own body lively and durable for half an hour, or an hour, when I had on no clothes. I do not say, however, that the friction does not increase it." It appeared to be clearly proved that there is no species of electricity connected with the human subject, which is at all under the regulation of the will; instances of this kind from among the animal kingdom we now proceed briefly to mention.

Chap. VII.

J. J. Hemmer, *Transactions of the Electoral Society of Manheim*, vol. vi., or *Phil. Mag.* 1799, vol. v. p. 1 and 140.

2. *Electricity of the Raia Torpedo.*

Raia torpedo

(197.) The electrical properties of this fish having been known from a very early period, may be a sufficient reason for assigning to it the foremost place in our list of spontaneously electrical animals. Of the accounts handed down to us in the writings of Pliny, Oppian, and others, we have already made some mention, and, therefore, may be allowed to pass on to the experimental researches of modern naturalists.

Redi, who published in 1678 his *Experimenta circa res diversas Naturales*, mentions the imperfect observations of the fishermen upon the properties of this animal. About the same time Lorenzini published an account of its anatomical structure, with illustrative engravings.

Kæmpfer, in 1702, describes in his *Amœnitates Exoticæ*, some experiments which he made upon the torpedo. The most singular is, that any person might avoid all sensation of the shock by holding his breath at the same time that he touched the animal. This, which at first appears improbable, has been confirmed by the accurate observations of Mr. Walsh.

In Dr. Bancroft's *Natural History of Guiana* the electrical nature of the torpedo's power is first suspected; but little was effected towards the proof of this fact, until the valuable papers of Mr. Walsh appeared in the *Phil. Trans.* for 1773 and 1775. He placed a live torpedo upon a wet napkin, and formed a communication through five persons, who were all insulated; the person at one extremity touched some water into which a wire from the wet napkin terminated; and the last in the series had a similar mode of communication with a wire which at intervals could be brought in contact with the back of the torpedo. In this manner shocks were communicated to the five, and also to eight persons. In the general result it appeared that, as in the case of common electricity, glass and such substances intercepted the shock, while metals and those bodies known as ordinary conductors suffered its transmission. Walsh was unable, however, to affect the balls of an electrometer, or to produce any appearance of a spark by the electricity of this fish.

In the next place it appeared desirable to make a similar series of experiments with the fish immersed in water instead of air. Mr. Walsh, therefore, held a large and powerful torpedo in both his hands, grasping the electric organs both above and below; and then plunged it a foot beneath the surface of some water, and again raised it an equal height in the air. The moment the lower surface of the torpedo touched the water in descending, he always gave a violent shock; and a still more powerful one was produced at the instant that the same surface emerged from the water in ascending. Both these shocks were attended with a contortion of the body, as if the animal were anxious to make its escape. The intensity of the shock under water was scarcely one-fourth of that at the surface, and not much more than one-fourth of those given in the air. The number of the shocks appeared to be about twenty in a minute.

The shock of the torpedo was in general not perceptible beyond the finger with which it was touched; and out of 200 shocks Mr. Walsh found one only which affected him above the elbow. If the torpedo were insulated it was able to give forty or fifty shocks without any diminution of force, to persons who were also insulated. Each shock produced by the animal is attended with a depression of its eyes; and as this appearance seemed of invariable recurrence, Mr. Walsh could tell, by observing the eyes, when the animal attempted to produce an electrical discharge, even upon non-conducting bodies.

Mr. Walsh then put the torpedo into a flat basket open at the top, but secured by a net with wide meshes, and thus confined, the animal was lowered about a foot into the water. If then it was touched through the meshes by a single finger, on one of its electric organs, the other hand being held at a distance in the water, shocks were distinctly felt in both hands; but when the circuit was made by applying one finger above and the thumb below to one organ only, a shock was experienced twice as great as the former one, when two arms formed the circuit.

The torpedo in its basket, having been raised to within three inches of the surface of the water, was then touched with a short iron bolt held in one hand, half out and half within the water, while the other hand was immersed in the water at some distance; strong shocks passing through the bolt were experienced in both hands. By forming the communication through a wet hempen cord, the shock was conveyed as before.

By suspending a powerful torpedo in a net, and frequently dipping it into the water, slight shocks were communicated through the net to the persons holding it.

Mr. Walsh explains the difference between the effects of the electricity of the torpedo and of the Leyden jar, on these principles. The same quantity of electricity will produce very different effects according to the degree of condensation in which it is detained. A small jar having six square inches of coated surface will be able to force its charge through an inch of air, and exhibit attraction and repulsion, as well as the snap and spark. But by distributing the same quantity of electricity over two large connected jars having a coated surface of 400 times the extent of the small phial, effects analogous to those of the torpedo are produced. In this attenuated state the change will not pass through the hundredth part of an inch of air; the spark and snap, and the approach and recession of light bodies will no longer be produced; a point brought near will not be able to draw off the charge; and yet in this state of feeble intensity it will run through a considerable circuit of conducting bodies, and during its passage will produce sensible effects upon the animal system.

In 1773, Dr. Ingenhouz made many experiments at Leghorn upon the torpedo; he describes the shocks as producing the same sensation as if a great number of very small electrical jars were discharged through his head in very rapid succession. Sometimes the shock was very feeble, and at other times so strong as almost to oblige him to quit his hold of the animal. By pinching the fish with his nails, it did not give either more or fewer shocks than when not so irritated; but by folding the body, or bending its right side to the left, the shocks were rendered more frequent.

Other researches upon the irritability of the torpedo have been made by Spallanzani. He found the shock to be most powerful when the animal was laid upon a plate of glass. He states that in irritating the torpedo, he always obtained the shock, whether it was out of the water or in it If instead of irritating the back, he irritated the breast gently, he received a shock, but not so frequently as by irritating the back. Spallanzani found that some minutes before the torpedo expired the shocks were not given at intervals, as in the healthy state of the animal, but were changed into a reiterated succession of small shocks. During a space of seven minutes of this action his fingers experienced 316 shocks; the shocks then suffered an interruption, and the animal immediately before it died gave a few very languid shocks. Spallanzani discovered also the singular fact, that even the fœtus of a torpedo possessed the same electrical property even before it was born.

The most recent experiments of importance upon the electric irritability of the torpedo, were made in 1805, by MM. Humboldt and Gay Lussac. The following has been given as a succinct account of the results obtained by these admirable experimentalists.

1. "A person much in the habit of receiving electric shocks, can support with some difficulty the shock of a vigorous torpedo fourteen inches long. The action of the torpedo below water is not perceptible. till it is raised above the surface of the water.

2. "Before each shock, the torpedo moves its pectoral fins in a convulsive manner, and the violence of the shock is always proportional to the extent of the surface of contact.

3. "The organs of the torpedo cannot be discharged by us at our pleasure, nor does it always communicate a shock when touched. It must be irritated before it gives the shock, and in all probability it does not keep its electric organs charged. It charges them, however, with astonishing quickness, and therefore is capable of giving a long series of shocks.

4. "The shock is experienced, when a single finger is applied to a single surface of the electric organs, or when the two hands are placed, one on the upper, and one on the under surface at the same time; and in both these cases the shock is equally communicated whether the person be insulated or not.

5. "If an insulated person touches the torpedo with his finger, it must be in immediate contact; as no shock is received if the animal is touched with a key, or any other conducting body.

6. "The torpedo being placed upon a metallic plate, so that the inferior surface of its electric organ touched the metal, the hand which supported the plate felt no

shock, although the animal was irritated by another insulated person, and when it was obvious from the convulsive motions of its pectoral fins, that it was in a state of powerful action.

7. "If on the contrary, a person support with his left hand the torpedo placed on a metallic plate, and if he touches with his right hand the upper surface of the electric organ, a violent commotion will be felt in both his arms at the same instant.

8. "A similar shock will be received if the fish is placed between two metallic plates, the edges of which do not touch, and if a person applies a hand to each plate at the same instant.

9. "If under the circumstances of the preceding experiments, there be a connection between the edges of the two plates, no shock will be experienced; as a communication is now formed between the two surfaces of the organ.

10. "The organs of the torpedo do not affect the most delicate electrometer. Every method of communicating a charge to the condenser of Volta was tried in vain.

11. "A circle of connection being formed, by a number of persons, between the upper and under surfaces of the organs, they received no shock till their hands were moistened in water. The shock was equally felt, when two persons who had their right hand applied to the torpedo, instead of taking hold of each others left hands, plunged a piece of metal into a drop of water placed upon an insulated body.

12. "By substituting flame in place of a drop of water, no sensation was experienced till the two pointed pieces of metal came in contact with the flame.

13. "No shock will be experienced, either in air or below water, unless the body of the electric fish is immediately touched. The torpedo is unable to communicate its shock through a layer of water, however thin.

14. "The least injury done to the brain of this animal prevents its electrical action."

(198.) Having thus made our readers acquainted with the more striking peculiarities of this curious fish, we may in the next place give the detail of its anatomical structure from the Paper of the celebrated Hunter, published in the *Phil. Trans.* for 1773.

"The electric organs of the torpedo are placed on each side of the cranium and gills, reaching from thence to the semicircular cartilages of each great fin, and extending longitudinally from the anterior extremity of the animal to the transverse cartilage which divides the thorax from the abdomen; and within these limits they occupy the whole space between the skin of the upper and under surfaces; they are thickest at the edges near the centre of the fish, and become gradually thinner toward the extremities. Each electric organ at its inner longitudinal edge, is unequally hollowed, being exactly fitted to the irregular projection of the cranium and gills. The outer longitudinal edge is a convex elliptic curve. The anterior extremity of each organ makes the section of a small circle; and the posterior extremity makes nearly a right angle with the inner edge. Each organ is attached to the surrounding parts by a close cellular membrane, and also by short and strong tendinous fibres, which pass directly across from its outer edge to the semicircular cartilages. They are covered, above and below, by the common skin of the animal, under which there is a thin fascia spread over the whole organ. This is composed of fibres, which run longitudinally, and in the direction of the body of the animal. These fibres appear to be perforated in innumerable places, which gives the fascia the appearance of being reticulated. Its edges all around are closely connected to the skin, and at the last appear to be lost or to degenerate into the common cellular membrane of the skin. Immediately under this is another membrane exactly of the same kind; the fibres of which in some measure decussate those of the former, passing from the middle line of the body outwards and backwards. The inner edge of this is lost with the first described; the anterior, outer, and posterior edges, are partly attached to the semicircular cartilages, and partly lost in the common cellular membrane.

"This inner fascia appears to be continued into the electric organ, by so many processes, and thereby makes the membranous sides, or sheaths of the columns, which are presently to be described; and between these processes the fascia covers the end of each column making the outermost or first partition. Each organ of the fish under consideration is about five inches in length, and at the anterior end three in breadth, though it is but little more than half an inch broad at the posterior extremity. Each consists wholly of perpendicular columns, reaching from the upper to the under surface of the body, and varying in their length according to the thickness of the parts of the body where they are placed; the longest column being about an inch and an half, the shortest about one-fourth of an inch in length, and their diameter about $\frac{2}{10}$ths of an inch.

"The figures of the columns are very irregular, varying according to situation and other circumstances. The greatest number of them are either irregular hexagons, or irregular pentagons; but from the irregularity of some of them, it happens that a pretty regular quadrangular column is sometimes formed. Those of the exterior one, are either quadrangular or hexagonal; having one side external, two lateral, and either one or two internal. In this second row they are mostly pentagonal. Their coats are very thin, and seem transparent, closely connected with each other, having a kind of loose net work of tendinous fibres passing transversely and obliquely between the columns, and uniting them more firmly together; these are mostly observable where the large trunks of the nerves pass. The columns are also attached by strong inelastic fibres, passing directly from the one to the other.

"The number of columns in different torpedos, of the size of that offered to the Society, (which was about eighteen inches long and twelve broad, and about two inches thick in the thickest part,) appeared to be about 470 in each organ; but the number varies according to the size of the fish."

In a very large torpedo found on the British coast, which was four and a half feet long, and weighed seventy-three pounds, the number of columns in one electric organ was 1182. Walsh, *Phil. Trans.* 1774.

"The columns now described, increase not only in size but in number during the growth of the animal; new ones forming perhaps every year on the exterior edges, as they are much the smallest. This process may be similar to the formation of teeth in the human jaw, as it increases. Each column is divided by horizontal partitions, placed over each other at very small distances, and forming numerous interstices, which appear to contain a fluid. These partitions consist of a very thin membrane, considerably transparent. Their edges appear to be attached to one another, and the whole is attached by a fine cellular membrane to the inside of the columns. They are not totally detached from one another I have found them adhering at different places, by blood vessels passing from one another.

"The number of partitions contained in a column of one inch in length, of a torpedo which had been preserved in proof spirit, appeared on a careful examination to be 150; and the number in a given length of column, appears to be common to all sizes in the same state of humidity; for by drying them they may be greatly altered. Whence it appears probable that the increase in the length of a column, during the growth of the animal, does not enlarge the distance between each partition in proportion to that growth; but that new partitions are formed and added to the extremity of the column from the fascia.

"The partitions are very vascular; the arteries are branches from the veins of the gills, which convey the blood that has received the influence of respiration. They pass along with the nerves to the electric organ, and enter with them; they then ramify in every direction, into innumerable small branches on the sides of the columns, sending in from the circumference all around, on each partition, small arteries, which ramify and anastomose on it; and passing also from one partition to another, anastomose with the vessels of the adjacent partitions. The veins of the electric organ pass out close to the nerves, and run between the gills to the auricle of the heart.

"The nerves inserted into each electric organ, arise by three very large trunks from the lateral and posterior part of the brain. The first of these in its passage outwards, turns round a cartilage of the cranium, and sends a few branches to the first gill, and to the anterior part of the head, and then passes into the organ towards its anterior extremity. The second trunk enters the gills between the first and second openings, and after furnishing it with small branches passes into the organ near the middle. The third trunk after leaving the skull, divides into two branches, which pass to the electric organ through the gills; one between the second and third openings, the other between the third and fourth, giving small branches to the gill itself. These nerves having entered the organs, ramify in every direction between the columns, and send in small branches on each partition where they are lost.

"The magnitude and the number of the nerves bestowed on these organs in proportion to their size, must on reflection appear as extraordinary as the phenomena they afford. Nerves are given to parts either for sensation or action. Now if we except the more important senses of seeing, hearing, smelling, and tasting, which do not belong to the electric organs, there is no part, even of the most perfect animal, which in proportion to its size, is so liberally supplied with nerves; nor do the nerves seem necessary for any sensation which can be supposed to belong to the electric organs. And, with respect to action, there is no part of any animal with which I am acquainted, however strong and constant its natural actions may be, which has so great a proportion of nerves. If it be then probable that these nerves are not necessary for the purposes of sensation or action, may we not conclude that they are subservient to the formation, collection, or management, of the electric fluid; especially as it appears evident from Mr. Walsh's experiments, that the will of the animal does absolutely controul the electric powers of its body, which must depend upon the energy of the nerves."

M. Geoffroy St. Hilaire has by a recent examination, been enabled to bear testimony to the accuracy of Hunter's description of this fish. He states also, that a similar organic structure is found in other animals of the Raia genus, which nevertheless do not possess any electrical powers.

The singularity of action, manifested by the torpedo, led Walsh, and other experimentalists of the age, to attempt a full explanation of its properties, on the known principles of electricity. This was a task of considerable difficulty, as the shocks were sometimes obtained by contacts and connections to which the Leyden jar furnished no direct analogy.

In pursuance of these objects, Mr. Cavendish contrived an artificial torpedo. It was made of wood, connected with glass tubes and wires, and covered with a piece of sheep skin leather. To make the effect of this instrument more like that of the animal, with regard to the difference between the shock in and out of water, it was necessary to substitute thick leather in place of the wood, and with this improvement the apparatus succeeded admirably. In air the sensation of the shock was sensible at the elbows, but under water it was felt chiefly at the hands. By touching this torpedo with one hand under water, a shock was obtained as strong as if it had been touched by both. Being touched under water with two metallic spoons, it gave no shock, but in air the shock was very strong.

Cavendish made also a comparative estimate between the strength of his artificial torpedo and that dissected by Mr. Hunter, with reference to surface. His own battery consisted of seventy-six feet of coated surface; and he calculated that the animal retained a charge fourteen times as great as that of the battery, or was equivalent to 1064 feet of coated glass.

The power of the animal to communicate a shock under water is explained on the principle of the different relative conducting powers of bodies; the shock preferring a long passage through a good conductor, to a comparatively short one through a substance of inferior capacity. It seemed also singular, that from the fish neither sound, nor spark, nor attraction, could by any means be made manifest. This led Mr. Cavendish to examine the effect of distributing a given quantity of electricity over a great extent of surface. His experiments led him to consider that the distance to which the spark will fly is, inversely, in rather a greater proportion than the square root of the number of jars. With regard to attraction and repulsion, Cavendish found, that in a large battery so weakly electrified that its shock will not pass through a chain, a pair of pith balls suspended from the discharging rod, do not exhibit any divergence.

Consult Lorenzini *Osservationi intorno alle Torpedini*, Firenze, 1678, or *Philosophical Transactions*, 1681, p. 42; Reaumur, *Mém. Acad. Par.* 1714, p. 344; Bancroft, *Natural History of Guiana*, p. 194; Walsh, *Phil. Trans.* 1773, p. 461; Hunter, *Phil. Trans.* 1773, p. 481; Walsh, *Phil. Trans.* 1775, p. 465; Ingenhouz, *Phil. Trans.* 1775, p. 1; Pringle's *Discourse on the Torpedo*, Lond. 1775; Vassali Eandi, *Jour. de Phys.* vol. xlix. p. 69; Spallanzani, *Jour. de Phys.* vol. xxiii. p. 217; Bertholon, *de l'Electricité du Corps Humain*, tom. i. p. 172; Cavendish, *Phil. Trans.* 1776, p. 196; Geoffroy, Tilloch's *Mag.* vol. xv. p. 126, from *An. du Mus.*; Volta, *An. de Chimie*, 1802, p. 255; Humboldt and Gay Lussac, *An. de Chimie*, 1805, or *Phil. Mag.* vol. xxiii. p. 356; Nicholson's *Jour.* 4to. vol. i. p. 355; Bryant, *American Trans.* vol. ii. p. 144.

3. *Electricity of the Gymnotus electricus.*

(199.) The electrical properties of this fish were first made public by M. Richer, who had been sent out for the purpose of measuring the length of the seconds pendulum at Cayenne. It is sometimes called the electrical eel of Surinam; and numerous and curious as are the experiments which have been made upon this animal, the hypotheses which writers and naturalists have advanced upon the subject are not less so.

Redi supposed that the benumbing effects depended upon a subtle but substantial emanation proceeding from the fish, which, entering within the pores of other bodies, produced by its accumulation the disturbance of a shock. Schilling imagined that the action of the gymnotus was of a magnetic nature, and makes mention of certain experiments, in which the loadstone and the fish seemed to produce an influence upon each other.

Omitting, however, these speculations, which are more curious than useful, and which, if necessary, may be traced from the references at the end of this section, we will only introduce a short abstract of the known phenomena of the electrical eel, and then give some description of the structure of the animal, from the researches of Dr. Hunter, Mr. Walsh, and Dr. Williamson.

By touching the eel with one hand, a shock is perceived in the fingers, the wrist, or the elbow; but by making the contact with an iron rod twelve inches long, the shock was perceptible in the finger and thumb only by which the rod was held.

The hand of one person being held in water at the distance of three feet from the animal, upon a second person irritating the eel, the former will feel a shock, but of less violence than if he touched the animal itself.

Dr. Williamson put a cat-fish into the same vessel of water with an eel, and then dipped his own hand into the water also. The gymnotus swam up to the fish, but turned away without offering any violence to it. It soon returned, however, and after regarding the cat attentively for some seconds, gave it a shock which made it turn up its belly and continue motionless. The shock was perceptible to Dr. Williamson t the same time. Whenever fish that had been thus rendered motionless were removed to another vessel they recovered.

By irritating the gymnotus with one hand, and holding the other at some distance in the water, a shock was perceived in both arms like that of the Leyden jar. A similar effect might be produced by touching the water with a wet stick, irritating the animal with the other hand as before. Two persons also might, by joining hands, share in the effects of this experiment, as with a charged electrical jar.

When one of two persons joining hands touched the head roughly, while at the same time the other touched the tail gently, they both received a severe shock.

When the first of eight or ten persons, with joined hands, touched the eel, while the last put his hand into the water at some distance from it, they all received a gentle shock.

When the first of the eight pinched the tail, while the last touched the head, they all received a severe shock.

When two persons laid hold of the two extremities of a brass chain, and one of them put his hand into the water, while the other touched and irritated the eel, the shock affected both.

If a silk handkerchief be wrapped round the hand, and the eel be touched with it, no shock is experienced, though another person, who puts his hand into the water at a little distance from the eel, will feel the shock.

The connection between two persons was formed by various substances, such as charcoal, iron, brass, dry wood, glass, silk, &c. and it was always found that the shock of the eel was conveyed through those substances that conduct common electricity, while it refused to pass through non-conductors. The shock was not conveyed by a brass chain, unless the chain were stretched, or the shock severe.

An insulated person being electrified by the eel, he exhibited no marks of electricity; nor did cork balls diverge when suspended by silk threads over the eel's back, or when touched by the insulated person when he received the shock.

Dr. Williamson made several attempts to render the passage of the shock perceptible by the spark, but without success. Mr. Walsh, however, by making a minute separation in a piece of foil between two plates of glass, on the principle of the luminous word, obtained a visible spark.

On the whole, Dr. Williamson concludes that the gymnotus has the power of communicating a shock to those animals that touch it, either directly or by the intervention of a conductor; that this effect depends solely upon the will of the animal; and the magnitude of the shock is dependant also within certain limits upon some act of volition on the part of the fish. That the shock does not at all depend upon any muscular action in the animal, but upon some process purely electrical. M. Humboldt describes, in his *Travels in South America*, a singular method of catching the gymnoti, by driving wild horses into a lake which abounds with them. The fish are wearied or exhausted by their efforts against the horses, and then taken; but such is the violence of the shocks which they give, that some of the horses are drowned before they can recover from the paralysing shocks of the eels. He states also, that in giving the most powerful shocks, the gymnotus does not make any motion of the head, eyes, or fins, like the torpedo.

Gymnoti are described of different sizes. One examined by Hunter was not three feet long. Dr. Garden describes one three feet eight in length, and Dr. Bancroft, when in Guiana, was told of some having been seen in the Surinam river upwards of twenty feet in length, the shock of which was instantly fatal.

Anatomical structure.

Upon dissection, Hunter found that the electrical organs of the gymnotus occupy nearly one-half of that part of the flesh in which they are placed, and constitute probably more than one-third of the whole fish. The animal possesses two pair of electrical organs of different sizes, and placed on different sides. One large organ occupies the whole of the lower end and the lateral part of the body, constituting the thickness of the fore part of the animal, and stretching from the abdomen to near the end of the tail, where it terminates almost in a point. The two organs are separated at the upper part by the muscles of the back, at the middle part by the air bag, and at the lower part by the middle partition. The smaller organ extends along the lower edge of the animal, almost as far as the other, terminating almost insensibly near the end of the tail. The two organs are separated from one another by the middle muscle, and by the bones in which the fins are articulated. In order to perceive the large organ, it is necessary merely to remove the skin which adheres to it by a loose cellular membrane; but in order to perceive the small organ, we must remove the long row of small muscles which move the fin. The organs consist of two parts, viz. flat partitions or septæ, and cross divisions between them. These septæ are very thin and tender membranes, placed parallel to one another; they stretch in the direction of the length of the fish; and having their breadth nearly equal to the semidiameter of the animal's body. The length of the septæ differs, some being as long as the whole body. The distances between the septæ vary with the size of the fishes. In one two feet four inches long, their distance was nearly half an inch, and in the broadest part of the organ, which was an inch and a quarter, there were thirty-four septæ. The small organ has the same kind of septæ, but they stretch in a direction somewhat serpentine. Their distance is only about $\frac{1}{56}$th part of an inch; and in the breadth of the organ which is half an inch, there are fourteen septæ. Hunter considers that the septæ answer the same purpose as the columns in the torpedo, forming walls or abutments for the subdivisions, and constituting so many distinct organs. These septæ are intersected transversely by very thin plates or membranes, whose breadth is the distance between any two septæ, and therefore of different breadths in different parts; broadest at the edge which is next the skin, and narrowest at that edge next to the centre of the body, or to the middle partition which divides the two organs. The lengths of these membranes are equal to the breadths of the septæ, between which they are situate, and there is a regular series of them from one end of any two septæ to the other end. In one inch there were 240 of these transverse membranes.

Consult Richer, *Mém. Acad. Par.* 1677, tom. i. p. 116; Ibid. tom. vii. part ii. p. 92; Condamine, *Relation d'un Voyage, &c. Mém. Acad. Par.* 1745, p. 466; Perrere, *Histoire de France Equinoxiale*; Fermin, *Description de Surinam*, tom. ii. p. 261; Muschenbroeck, *Mém. Acad.* 1760, *Hist.* p. 21; Bancroft's *History of Guiana*; Schilling, *Mém. Acad. Berlin*, 1775, p. 6; Williamson, *Phil. Trans.* 1775, p. 94; Gordon, *Phil. Trans.* 1775, p. 102; Walsh, *Phil. Trans.* 1775; Hunter, *Phil. Trans.* 1775, p. 395; Van Swinden, *Recueil des Mémoires sur l'Analogie de l'Electricité et du Magnétisme*, 1786, vol. i. p. 439; Lacepede, *Hist. Nat. des Poissons*, tom. ii.; Humboldt's *Personal Narrative.*

4. *Electricity of the Silurus electricus.*

Silu elec

(200.) This fish, as far as is at present known, is peculiar to some of the rivers of Africa. Adanson described it from the Niger, and Forskel, though he gave to it another name, found it in the Nile. By the Egyptians it is called Raasch, a name which is also applied to the torpedo; they eat its flesh, and cure the skin with salt, for medicinal purposes. The Negroes of Senegal term it Onanienar; and, from its electrical properties, the French have sometimes called it *le Trembleur du Senegal.*

The length of this silurus is about twenty inches. It is broad towards the fore part, and of a dark ash colour, with blackish spots towards the tail. By laying the fish upon one hand, and touching it with a metal rod held in the other, an electrical shock is distinctly perceptible, but by no means so strong as that given by the torpedo.

The anatomical structure of this fish has been described by M. Geoffroy, who states that the organs, by which the electrical effect is produced, are much less complicated than those adapted to a similar purpose in the torpedo or gymnotus. There is lying immediately beneath the skin, and encircling the whole animal, a mass of cellular substance so thick and compact, as to appear to consist of a stratum of fat. By microscopic investigation, however, it is evident that this is composed of a tissue of tendinous or aponeurotic fibres, interlacing each other, and forming a distinctly reticulated mass, containing, in the interstices or cells, an albuminous or gelatinous matter. All connection with the inside, is cut off by a strong aponeurosis extending over the whole reticulation, and adhering very closely to it; and above this is a thick stratum of fatty matter. The nerves, distributed over the electric organ of the fish, proceed from the brain, and are analogous to those found in all other fishes beneath the lateral line of the body. The direction and arrangement of the eighth pair of nerves is peculiar to this species alone. As they issue from the cranium they approach each other and descend through the substance of the first vertebra; entering by distinct orifices, but reissuing from one common perforation on the opposite side After reascending, they suddenly divide and proceed under each of the lateral lines, passing between the abdominal muscles and the aponeurosis, which extends over the articulated organ. Large branches then separate and pass beneath the skin, proceeding to the right and left of the principal nerve. These branches, of which there are twelve or fifteen on each side, penetrate the aponeurosis, lining the inner surface of the cellular tissue, and are there lost.

Adanson, *Voyage au Senegal*, 1757, p. 153; *Jour. de Phys.* vol. xxvii. p. 139; Broussonet, *Mém. Acad. Par.* 1782, p. 692; Geoffroi *Bulletin de la Société Philomathique*, tom. iii. p. 169; *Phil. Mag.* vol. xv. p. 126.

5. *Electricity of the Trichiurus Indicus.*

Trich Indic

(201.) Of this fish, which is said to inhabit the Indian seas, and to be endowed with electrical properties, we regret that it is not in our power to communicate any information beyond this bare mention of its name.

6. *Electricity of the Tetraodon electricus.*

(202.) The *Philosophical Transactions* for 1786, contains the only account, with which we are acquainted, of this fish, which seems to possess electrical powers of considerable intensity. It was discovered by Lieutenant William Patterson, in a voyage to the East Indies. The fish is described as being seven inches long, two and a half broad, and as having a long projecting mouth. The colour of the back is a dark brown, the belly is sea-green, the sides yellow, and the fins and tail sandy green. The whole of the body is covered with red, green, and white spots, the latter being particularly bright. The eyes of the fish are large, with a red iris, having its outward edge tinged with yellow. Mr. Patterson caught the fish in cavities among coral rocks, where the water had a temperature of from 56° to 60° Fahrenheit; off the island of Joanna. Having caught two of them in a linen bag, he attempted to take one of them in his hand, when he received so severe an electrical shock, as to oblige him to quit his hold. He then carried them a distance of two miles to the camp, but on his arrival found that one of them had died, and the other was already reduced to a state of extreme debility. The fish was then put into a tub of water, and the surgeon of the regiment attempting to seize it with both his hands, received a distinct electrical shock. The adjutant also, upon touching the back with his finger, experienced the electrical effects, but in a much slighter degree. *Phil. Trans.* vol. lxxvi. p. 382.

§ III. *Change of temperature.*

(203.) The subjects for experiment connected with this section, are derived principally from the mineral kingdom. All, in fact, that we feel sufficiently acquainted with to lay before our readers; but at the same time we wish to point out a curious paper of M. Dessaignes, in the second volume of the *Annales de Chimie et du Physique*, in which many experiments are recorded, which, if accurate, will prove that metallic bodies are capable of electric excitation, by the processes of heating and cooling only. The description of these researches forcibly recalls to our attention the modern thermo-electric processes, and as it is now proved beyond the possibility of doubt, that that species of electric excitation which affects the magnetic needle, may be developed in metals by the application of heat only, there is a strong analogy in favour of the supposition, that ordinary electricity is at the same time elicited, although its quantity may be so small as to render its presence difficult of detection.

The following is the order in which the minerals possessed of this property will come under our notice:

1. Boracite.
2. Topaz.
3. Axinite.
4. Mesotype.
5. Tourmaline.
6. Prehnite.
7. Calamine.
8. Sphene.

1. *Borate of magnesia* (*Boracite.*)

(204.) In 1791, the Abbé Haüy having received two crystals of this substance, undertook a careful examination of their physical characteristics. Having exposed them to the action of heat, he perceived upon presenting them to the electroscope, that they were possessed of electrical properties. The next point was to ascertain the position of their electric poles, which the analogy of the tourmaline had led him to expect. By turning the crystal about, opposite to the extremity of an excited needle, he was surprised by the attractions and repulsions, which succeeded each other with such rapidity, as to make it difficult to determine the points upon which the opposite electricities resided. Reasoning upon this new fact, and instituting a sort of comparison between the substance before him and the tourmaline; he considered that as the latter from its crystalline form possessed but one axis, which coincided with that of the nucleus, and that, consequently, it ought only to possess two electric poles, situate at the two extremities of that axis. The boracite, on the other hand, having a cube for its nucleus possessed four axes, each of which passed through two opposite solid angles; from whence it would follow that there ought to be eight electrical poles; two for each axis. Experiment verified this conjecture; and the position of the poles was found to be so arranged, that taken four and four with reference to each kind of electricity, each alternate one possessed the opposite property.

At that time M. Haüy had not carefully examined the facettes which modified the cubic crystal, but the remark which he had been led to make, upon the positions of the electrical poles, induced him to fix his attention particularly upon the points at which these poles were situate. He already knew that tourmalines deviated from the perfect symmetry of ordinary mineral forms, by a difference of conformation in their summits, due to the influence which the electrical forces had exerted upon their crystallization. And as the same disturbing forces had existed during the formation of the crystals of boracite, the Abbé expected that some analogy would be found to exist between these and the tourmalines with regard to external form; and in fact, by an attentive examination of the parts of the cube at which the opposite electricities appeared, he remarked that some presented solid angles complete, while others presented certain small planes which intercepted the opposite angles. The resinous electricity was situate at the complete angles, and the vitreous electricity at the facettes opposed to those angles.

Some time afterwards having received crystals of a second variety; he found that these had all their solid angles replaced by planes, and as the same took place with regard to their edges also, they appeared at first to be only cubes truncated upon all their solid angles and all their edges, and such in fact was the description given of them by Westrumb and others, who had examined them. But upon this hypothesis the symmetry would not have undergone any alteration, and yet every thing seemed to point out some such change; or else symmetry would itself become anomalous in exhibiting itself upon certain crystals, while others presented dissimilarity in the forms of their opposite poles. By a more minute examination, however, it appeared that around the facettes, which had replaced the solid angles, which were complete in the first variety, there were three other small planes, to which there were no corresponding ones at the opposite extremity of each axis. These were exceedingly small, and would have escaped the eye, had not their existence been connected with a certain physical fact, which called for a search after their presence. In this case it might be said that crystallization had only unwillingly submitted to the force which tended to remove it from its ordinary course.

Every variety of this mineral subsequently examined, presented the same variation from the laws of symmetry; it would appear that the two fluids, which are endowed with opposite properties, have introduced some discordancy among the harmony of their crystalline form. Of the eight solid angles of the cube, four are always replaced by single planes; the remaining four either remain untouched, or are replaced by more than one plane. The vitreous electricity always resides at the former angles, and the resinous upon the latter.

The electricity of these crystals is generally sensibly less than that of the tourmaline. Experiments for its exhibition require much delicacy, especially with respect to the repulsive effects which exist only throughout a very small space; so that to obtain the repulsive action of a resinous pole, upon a body resinously electrified, it is essential that this latter body should be directed exactly to the repulsive point, otherwise attraction will take place towards the adjacent parts, which are in their natural state, or nearly so.

Haüy, *An. de Chimie*, tom. ix. p. 59; Ibid. *Traité de Minéralogie*, vol. ii. p. 60. edit. 2d.

2. *Topaz* (*silicious fluate of alumina.*)

Topaz.

(205.) The excitability of the topaz upon the application of heat, was discovered by Mr. Canton in 1760. For the most accurate examination of its habitudes, we must, however, again refer to the Abbé Haüy. He states, that at first he had supposed the Brazilian and Siberian topazes alone possessed this property; but that he had subsequently discovered it in some of the Saxony ones, although these required to be insulated previously to its developement. The Siberian varieties are capable of retaining the electricity acquired by heat, for many hours.

The transparent topazes only require a slight friction for the developement of their electrical properties, or even manifest them upon pressure between the fingers. The duration of excitation upon this mineral, is, perhaps, greater than upon any other, with the exception of transparent carbonate of lime. The blue topazes of Scotland have similar properties.

The electric poles of the topaz are situate upon the two opposite summits of the secondary crystal, but among some topazes from Siberia, Haüy recognised one with a singular property, which he thus describes:

"In attempting to determine its electric poles, I observed that both its extremities were resinously electrified, while the intermediate part of the crystal gave indications of vitreous electricity. This fact has a considerable degree of similarity to one presented by certain magnets which contain a consecutive series of opposite poles. I am not aware that a series of consecutive poles has been before remarked in an electrified body."

Priestley's *Hist. Elect.* p. 324; Wilson, *Phil. Trans.* 1762, p. 44; Haüy, *An. de Mus.* No. 5. p. 350; Ibid. No. 15. p. 1; Ibid. *Traité de Minéralogie*, vol. ii. p. 153. edit. 2d.

3. *Axinite.*

Axinit

(206.) It was first remarked by M. Brard, that some crystals of this mineral became electric by heat. Upon this, Haüy attentively examined many crystals of axinite, and found several among them departing from the perfectly symmetrical form; and such were precisely the specimens wherein it was possible to develope electrical excitation by this method. A more minute examination of the crystalline forms of this substance, with a comparative reference to its electrical properties, was a task which, had life been longer continued to this distinguished mineralogist, it was his intention to have undertaken.

Brard, *Manuel du Minéralogiste et du Géologue Voyageur*; Haüy, *Traité de Minéralogie*, vol. ii. p. 560. edit. 2d.

4. *Mesotype.*

Mesot

(207.) M. Haüy has added this mineral to the number of those in which heat is capable of developing electrical excitation. Some crystals have this property, others have not; but in one fragment the Abbé was able to recognise the distinct effects of electrical polarity.

The analogy presented by all minerals thus circumstanced, would lead to the supposition that those crystals which are possessed of this property, are not perfecly symmetrical in their forms; but this is a subject left for the future researches of the mineralogist.

Haüy, *Jour. des Mines*, No. xiv. p. 87; Ibid. *Traité de Minéralogie*, vol. iii. p. 160. edit. 2d.

5. *Tourmaline.*

Tourm line.

(208.) In the historical introduction to this article, we have mentioned the description by Theophrastus of a stone, the *lyncurium*, of great hardness, very difficult to polish, used for seals, and possessing the same properties as amber in the attraction of light bodies. Dr. Watson has ably identified this stone with the *tourmaline* of modern mineralogists, and the singularity of its electrical affections, has brought it under the notice of some of the most acute modern experimentalists.

In the year 1717, M. Lemery, of the French Academy, exhibited to the members of that body, a specimen of this mineral from Ceylon. In his Memoir he styles it *pierre de l'Isle de Ceylon, qui attire et répousse différens corps, mais d'une manière différente de l'aimant.* Linnæus, mentioning these experiments of Lemery, gives to the stone the name of the *lapis electricus.*

The Duke de Noya states, in his Treatise, that during his residence at Naples, in the year 1743, Count Pichetti, the King's Secretary, informed him that he had seen at Constantinople a stone, called tourmaline, which was possessed of attractive and repulsive properties. This circumstance he had forgotten, until the year 1758, the sight of some more of these gems in Holland brought the fact to his remembrance. He then purchased the specimens, and, in conjunction with MM. Daubenton and Adanson, made a series of experiments, and published the results which they obtained. In 1756, however, Æpinus published, in the *Memoirs of the Berlin Academy*, a paper, *De quibusdam experimentis electricis notabilioribus*; these experiments had been made upon two crystals of tourmaline, with which he had been furnished by Lechman. Mr. Wilson and Dr. Priestley were also industrious labourers in these fields of research.

Should any description of the tourmaline be thought necessary, it may thus be summarily given. It has every variety of colour from black, deep blue, deep green, brown, to a light green, hair brown or yellow. S. G. 3—3·4. Scratches glass. Is doubly refractive in a slight degree. Is frequently transparent in a direction perpendicular to the axis of its primitive crystals, but perfectly opaque in the direction of that axis. Its crystals are usually prisms, having an odd number of lateral planes, terminated by summits of three, six, nine, or more faces. Fuses before the blowpipe into a white or grey enamel. The electricity developed by friction is vitreous, but when two tourmalines are rubbed against each other, the one acquires the vitreous, the other the resinous electricity.

In addition to the excitability from heat, remarked by Lemery, Æpinus discovered the electrical polarity of the tourmaline; which he justly compared to the known effects of magnetism. He states, that if the mineral be brought to a heat between 99½ and 212 of Fahrenheit, one extremity acquires the vitreous, and the other the resinous electricity, so as to be capable of affecting a delicate electroscope. Mr. Wilson heated a tourmaline intensely in a fire for half an hour, and did not find that any diminution took place in its electrical properties. By plunging the stone into cold water, after it had been made red-hot, it was not broken to pieces, but became shivered throughout, and had lost its electrical powers. Mr. Canton, however, found in one case that he was able to destroy the electricity by heat, but that in some others he was not able to do so. This subject has attracted the attention of the Abbé Haüy also; he found that a tourmaline may be raised to such an intense degree of heat as to no longer exhibit any electricity. As the stone gradually cooled, the attractive properties again presented themselves; and, in fact, it appeared that the electric condition of the mineral underwent some very singular change, by which the poles were at intervals reversed, each passing through an intermediate state in which no excitation was apparent. This fact is analogous to some which the recent thermo-electric discoveries have brought to light.

Before we proceed to mention his results, we may be expected to describe the apparatus employed by the Abbé Haüy, in his researches upon the tourmaline. Fig. 41 represents a common support of steel *a b*, fixed into a foot *c c′*, and surmounted by a sharp steel point *a g*. The transverse part consists principally of a rectangular plate of metal *h k*, bent up square at its two extremities, in which two notches *o*, *r*, are cut. This plate is pierced in the middle by a circular hole which receives a small agate cap *x*, which is confined by a metal rim and two screws *s*, *z*. The needle *a g*, serving for a pivot, enters into a small cavity on the under side of the cap. Towards the extremities of the inferior surface of the plate *h k*, there are two wires affixed, *p i*, *u y*, directed rather obliquely from that surface, and terminated by two small balls *i*, *y*, both of metal. These balls are for the purpose of lowering the centre of gravity of the whole lamina, so that it may not fall during its rotation upon the pivot.

Suppose now that we wish to determine the two kinds of electricity which affect the poles of a tourmaline. The Spanish crystals are well adapted to these experiments. Having heated one of these, let it be placed in the notch *h k*, and present to both its extremities in succession, and at a small distance, some other substance excited by friction. Suppose, for example, this is a stick of wax, then the pole of the tourmaline, which manifests repulsion, will be the resinous one, and that which produces attraction will be the vitreous one. It is convenient to preserve one tourmaline, the poles of which have been ascertained and marked, to serve as a standard for the comparison of all others.

By examining the distribution of electricity upon an excited tourmaline, Haüy found that the quantitative arrangement of the fluid might be compared to that upon any excited cylinder; there being a space of considerable extent throughout the middle of the crystal, where it was almost impossible to detect the presence of any free electricity; and that the principal accumulation was at the extremities of the prism. If a tourmaline excited by heat, be broken into pieces, each fragment will be found to possess a vitreous and a resinous pole, in this respect presenting a fact strictly analogous to that which is observed in magnetic bodies.

Lemery, *Mém. Acad. Par.* 1717; Linnæi *Flora Zeylanica*; Æpinus, *Mem. Acad. Berol.* 1756; Noya Caraffa, *Essai sur le Tourmaline*, Paris, 1759; Wilson, *Phil. Trans.* 1759, p. 308; Watson, on the Lyncurium, *Phil. Trans.* 1759, 397; Æpinus, *Recueil de Mémoires sur la Tourmaline*, Petersburg, 1762, 8vo.; Bergman, *Phil. Trans.* 1766; Bergman's *Opusc.* vol. v. p. 401; Priestley, *History of Electricity*, p. 314; Ibid. *Own Experiments*, p. 697; Wilcke, *Abhandlungen der Königlichen Schwedischen Acad.* xxviii. p. 95, and xxx. p. 105; Zallinger, *von Tourmalin*, Vienna, 1779; Haüy, *Mém. Acad. Par.* 1785, p. 206; Napioni, *sul Lyncurio*, Rome, 1795, 4to.; Haüy, *Minéralogie*, vol. i. p. 206. edit. 2d.

6. *Prehnite.*

Prehnite.

(209.) The crystalline form of prehnite is a right rhomboidal prism. It is capable of becoming electrical by the application of heat; and the direction of its poles is found to be parallel with the smaller diagonal of the crystal; while in the mesotype, the direction of the electric poles corresponds with that of the axis of the crystal.

Haüy, *Minéralogie*, vol. ii. p. 604.

7. *Calamine.*

Calamine.

(210.) The electrical properties of this mineral, which is an oxide of zinc, were recognised by Haüy in 1785. It appears from his statement, that all those specimens which present appearances of crystallization are capable of excitement by heat; and that, like tourmaline, they are possessed of polarity; and also undergo the reversion of their poles, already remarked, during the process of cooling.

Haüy, *Minéralogie*, vol. iv. p. 180, edit. 2d.

Practical Electricity.

8. *Sphene; calcareo-silicious oxide of titanium.*

Sphene.

(211.) Of this mineral some of the crystals become electrical by heat. Haüy informs us, that in general the electricity which they acquire is but feeble, so that it can only be discovered by diligent search, but that its presence is indisputable. As in the case of axinite, it is only in some specimens that this property of thermo-electricity can be recognised.

Haüy, *Mém. Acad. Par.* 1785, p. 207; Haüy, *Minéralogie*, vol. iv. p. 362. edit. 2d.

(212.) It may not as yet have been sufficiently explained, that as far as observations have hitherto extended to a subject confessedly of great intricacy, the property of electro-polarity in mineral bodies is intimately connected with the phenomena of crystallization. Generally speaking, the corresponding parts of crystals are similar in their number, their form, and in the arrangement of their planes. But those crystals which become electrical by heat, depart from that strict symmetrical arrangement, so that one of those points, upon which the electricity resides, exhibits the result of decrements which have not taken place upon the opposite corresponding point.

The opinion of the Abbé Haüy, to whom science is indebted for this discovery, is, that during the formation of these crystals, the two electrical fluids exerted upon the laws of structure, certain opposite influences which have left their impression upon the crystalline form. That the crystals which possess these singularities of electrical action, are not symmetrical is true, as far as we at present know. This may be seen in tourmaline, boracite, axinite, and topaz, and although it has not been distinctly proved of the other thermo-electric minerals, yet the imperfection and smallness of their crystals seem to be the only reason which has left the generality of this law embarrassed with any degree of uncertainty. It is also found, that the resinous electricity invariably resides at that extremity of the electrical axis which has the smallest number of planes; and of course the vitreous electricity will appear upon that extreme which is the more complicated of the two. For instance, the most common variety of tourmaline, which has its extremities complete, consists of a prism having nine lateral planes, and at one summit three faces, corresponding with the planes of the primary form, while at the other summit are the corresponding three, and also three other planes, making six in all. The former summit is the position of the resinous, and the latter, that of the vitreous electrical pole. A similar irregularity has been already mentioned as belonging to the borate of magnesia.

Haüy, *Minéralogie*, vol. i. p. 204.

§ IV. *Electricity of the atmosphere.*

(213.) In the historical introduction to this article, some instances have already been mentioned, in which the electricity of the atmosphere produced phenomena of sufficient importance to attract the attention of the early naturalists and historians.

It was not, however, until about the middle of the eighteenth century that any accurate or scientific researches had been made on this subject. M. le Monnier communicated to the Academy of Sciences at Paris, the results of certain experiments made by himself at St. Germain en Laye, in the latter part of the year 1752. He had a pole fixed vertically into the ground, which, at a height of thirty-two French feet, bore an insulated tin point, from which a metallic wire conveyed the electricity to an electroscope, or any other convenient apparatus for its examination.

The general statement of his result is, that some electricity might always be detected in the atmosphere; that in dry weather it was scarcely perceptible at sunrise, but increased gradually until three or four o'clock in the afternoon; it then diminished until the evening fall of dew, at which time it increased, and by a subsequent diminution it became almost insensible at midnight.

The general variations in the electrical state of the atmosphere, have been patiently investigated by Mazeas, Beccaria, Kinnersley, De Luc, Read, Saussure, and others; but as these may be reduced to a tabular form, and more properly fall under the registers of the Meteorologist, we refer them to the article peculiarly devoted to that subject.

(214.) Dissimilar objects of pursuit, or the compulsion of local circumstances, have introduced a great and undescribable variety of instruments for the examination or reception of atmospheric electricity. All however may be reduced to three general forms. A common kite was employed by Franklin, Romas, Cavallo, and others. It requires no peculiarity of construction, except that a pointed wire must extend a short distance above the top of the kite, and to this must be attached a fine wire continuing down either within the string or along its course quite to the earth. Indications of electricity may almost always be obtained by elevating this apparatus; but on the approach of thunder clouds, the electricity is very powerful, and the experiment is one of great danger, unless proper precautions be made use of. These are described in the writings of Cavallo, Read, Cuthbertson, &c.

If, instead of being carried up by a kite, a considerable length of insulated wire be extended horizontally above the earth, it is found frequently to accumulate a very considerable quantity of electricity. Such were the conductors of Ronayne, Mr. Crosse, and some others.

The experiments of Mr. Read and Mr. Singer appear principally to have been made by means of a conductor placed vertically in the ground. The advantages of such an instrument would arise from its being constantly ready for use, and little exposed to injury, but for extent of elevation it is much inferior to the kite.

(215.) Dr. Wall, Grey, the Abbé Nollet, and several others, had observed certain instances of striking analogy between the electric sparks and the spontaneous discharges of the atmosphere, well known by the name of thunder and lightning. Franklin drew up a scheme exhibiting these analogies, professing an intention to submit the question to the test of experiment. Before, however, the American philosopher could put his design into execution, it would appear that Buffon had elevated a conducting-rod upon the tower of Montbar, and that Dallibard had obtained some splendid electrical effects by employing a similar apparatus. It would appear, from a decision of the Academy of Sciences, dated February 4, 1764, that M. de Romas was the first person who elevated an electrical kite; but it is also clear that Franklin ctical ctricity. verified his conjecture and completed his discovery, independently of the French experimentalists. Few experiments, or perhaps none, are attended with such imposing grandeur as those by which copious quantities of atmospheric electricity are intercepted, and exhibited in a state subservient to the will of man; but at the same time it must be remarked that none require greater caution owing to the danger necessarily attendant upon them.

(216.) Having thus briefly traced the discovery of the true nature of thunder and lightning, we cannot be surprised that philosophers should have attempted to apply their newly-acquired information, to the useful purpose of preventing those dreadful effects with which the spontaneous discharges of the atmospheric electricity had so frequently been attended.

As far as we can ascertain, Franklin was the first to propose the application of a conducting-rod to the exterior of a building, in order to protect it from the lightning. It appeared very clear, that if a cloud highly charged with electricity came within a small distance of a house, the mast of a ship, or a tree, a discharge might take place, and if the body were not throughout a good conductor, the passage of the fluid would be marked by those violent effects which we have so often described. But if, in such a case, a metal rod were affixed to the building, the electrical discharge might be quietly conducted away without further damage.

Conductors to buildings were then generally considered a mode of protecting them from lightning; but in this country a discussion arose among some of the Members of the Royal Society, whether these conductors should have their summits terminated by balls or points. The latter in the end were most generally adopted.

nductors r buildgs. (217.) The directions for the formation of proper conductors to buildings have been most clearly laid down by Mr. Morgan. The conductor should be formed of a rod of iron or copper, about half or three-quarters of an inch in diameter. Its point should reach four or five feet at least above the highest point of the building it is intended to protect, and its lower end must either terminate in a reservoir of water, or be affixed deeply into the earth. In large buildings it is advisable to have more than one of these rods, and great additional security will be obtained by nailing strips of lead round all the projecting points of the roof, at the same time allowing the lead to communicate freely with the vertical rods.

The conductors for ships, when employed, are made of chains, and affixed to the masts.

rora realis. (218.) How far the aurora borealis may be a true electrical discharge, or how far as recent experiments would almost lead one to suppose, it is only a visible state of a general current of electrical fluid always circulating in our terrestrial system, are points of difficulty which we must leave for further investigation. This only is known, that the changes of atmospheric electricity sometimes are continued, and sometimes not, during the exhibition of the aurora; and that no very strong bond of connection has yet been observed to subsist between them.

The fire of St. Elmo, so frequently seen upon the masts of vessels in the Mediterranean, and from very early times connected with the names of Castor and Pollux, meets with a very simple explanation on the principle of a pointed conductor imbibing electricity from a strongly excited atmosphere. On this ground also, there may be reason in the supposition of the sailors, who, invariably, consider this preternatural appearance as the forerunner of changes in the weather.

Very numerous have been the attempts to identify or connect electricity with the causes of water-spouts, meteors, and other terrestrial phenomena, but on these points little of certainty has yet been ascertained. A very considerable portion of the elaborate little Treatise on Electricity, by the late Lord Stanhope, is taken up with explaining what he termed the electrical returning stroke; a phenomenon now easily accounted for on the principles of electrical induction, while at the same time some of Lord Stanhope's cases are instances in which animals have been killed by a discharge proceeding from the earth and passing through them. Of this species of action numerous instances are now on record, and, indeed, it is evident, upon ordinary electrical principles, that if two clouds, or one cloud and the earth be oppositely excited and charged, the spark and the discharge may either pass from the cloud to the earth, or from the earth to the cloud, as circumstances to us imperceptible may direct.

(219.) The changes which have been already noticed, with reference to the electrical state of the atmosphere, may be supposed to have arisen from ordinary natural causes; those which may in some sense be considered as the production of artificial causes of impurity, have been carefully examined by Mr. Read, of Knightsbridge. He imagined that air, by being vitiated even in a small degree in various ways, as by respiration, putrefaction, &c. became resinously electrified. Electricity of vitiated air.

The room in which he usually sat was small and confined, and he found by means of the electrical doubler, that the air was usually in this state of resinous electricity, while that of an adjoining and larger room was in the opposite state. Considering that there was nothing to occasion this difference, except what might be attributed to the respiration and effluvium of his body, he thought it might be possible to apply that principle in producing a change in the electricity of the larger room. For this purpose he invited a gentleman to sit with him in that apartment after having closed the doors and windows, the day being still and warm, with the thermometer at 75°. After about twenty or thirty minutes, he found himself in a state of profuse perspiration, and, upon working the doubler, found, as he had expected, that the electricity had now changed to the resinous state.

The air of his sleeping-room was vitreous in the evening at his going to bed; but upon rising at six o'clock the following morning, it was found to be resinous. Mr. Read was also surprised to find the dispersion of electricity greatly increased by this state induced upon the atmosphere. He found also that the confined air in the upper part of his house was resinous, but that the kitchen and cellars were in the contrary state; but after the two kitchens had been filled with noxious effluvium by painting and whitewashing, the electricity became resinous.

Knightsbridge Charity-school, which, from the number of children confined in it, was liable to become filled with a very disagreeable smell, especially when the door and windows were shut, was frequently examined, and found to indicate strong resinous electricity; and the schoolmaster's parlour adjoining, was found to possess rather more than its due proportion of vitreous electricity.

By a similar examination of the wards of the Lock Hospital with the doubler, it was invariably found that the close and confined parts were resinously electrical; while the more open and better ventilated parts were as constantly in the vitreous state.

The doubler was placed upon a heap of the loppings and leaves of shrubs in a state of putrefaction, and with some difficulty a charge of weak resinous electricity was obtained from the ascending vapour. The surrounding atmosphere was positive. A hot-house filled with warm and moist air, was also found to be in the resinous state. *Phil. Trans.* 1794, p. 266.

For registers of atmospheric electricity, consult the article METEOROLOGY in this Work. Le Monnier, *Mém. Acad. Par.* 1752, p. 233, 240, 241; Mazeas, *Phil. Trans.* 1753, p. 377; Beccaria, *Electricita terrestre Atmospherica*, sec. 1087; Saussure, *Voyages dans les Alpes*, tom. iii. p. 306, 8vo.; Gardini, *De Influxu Electricitatis Atmosphericæ*, sec. 50; Ronayne, *Phil. Trans.* 1772; Cavallo, *Phil. Trans.* 1776 and 1777; Achard, *Mém. Acad. Berlin*, 1780, p. 14; also 1786, p. 13; Bennet, *Phil. Trans.* 1787, p. 288; Read, *Phil. Trans.* 1791, p. 185; 1792, p. 225; Read, *Summary View of the Electricity of the Earth and Atmosphere*, Lond. 1793; Cotte, *Mém. Acad. Par.* 1772; Erman, *Jour. de Phys.* vol. 1. p. 98.

On conductors for experiments, see Read, *Phil. Trans.* 1791, p. 185; 1792, p. 225; Cavallo, *Phil. Trans.* 1776, p. 407; Singer, *Electricity*, p. 281.

On conductors for buildings, consult Watson, *Phil. Trans.* 1764, p. 201; Wilson, *Phil. Trans.* p. 246; Franklin's *Letters*, p. 121; Wilson, *Phil. Trans.* 1773, p. 48; 1778, p. 232. 999; 1769, p. 160; 1770, p. 188; Le Roy, *Mém. Acad.* 1770, p. 53. 472. 588; 1773, p. 599; also *Phil. Trans.* 1773, p. 42; Henley, *Phil. Trans.* 1774, p. 133; Nairne, *Phil. Trans.* 1778, p. 823; Regnier, *Mém. de l' Institute*, vol. iv.; Blagden, *Phil. Trans.* 1782, p. 355; Stanhope, *Phil. Trans.* 1787, p. 30; Patterson, *Trans. Amer. Phil. Soc.* vol. iii. p. 321; Bertholon, *de l'Electricité des Météores*, tom. i. p. 193.

On electrical kites, see Franklin, *Phil. Trans.* 1751, p. 565; Cavallo, *Phil. Trans.* 1776, p. 407; also 1777, p. 48; Bertholon, *de l'Electricité des Météores*, vol. i. p. 51; Cavallo's *Complete Treatise*.

§ V. *Electricity developed in the evolution of gases or vapours.*

It is the opinion of some philosophers, that no chemical change can take place among the elementary molecules of bodies, without being attended by some electrical effect, although this effect may often be to us inappreciable. The considerations which this question involves will, with greater propriety, be brought forward under the head of Voltaic Electricity. In the instances however, which the title of this section enumerates, the excitation had been remarked and examined, long before that branch of science was known to the world. The precise physical distinction (if any such exist) between a gas and a vapour, can form no part of our present speculations, neither shall we here attempt to determine, whether in the instances about to be recited, depending upon chemical processes, the electricity evolved is due to the chemical change; that is to say, to the new modification undergone by the force of affinity; or simply to the physical change experienced by some one or more of the elementary molecules of the substance acted upon. By this species of generalization we class together the effects produced during the vaporization of a liquid; and during the disengagement of a gas from its state of combination, so that what before was a component part in a solid body, is enabled to become an aeriform fluid.

Vapou

(220.) The earliest remarks with which we are acquainted, referring to this point, are from two of the most illustrious philosophers of modern times, MM. Lavoisier and La Place. They state, that bodies in passing from the solid or liquid state to that of vapour; and conversely, in returning from the aeriform condition to the liquid or solid state, give unequivocal signs of either positive or negative electricity. In these researches they employed two kinds of apparatus; in both the substance from which the vapour was produced, was insulated by varnished glass supports. If they had reason to suppose that the disengagement or absorption of electric matter would be slight and momentary, they allowed the vessel or substance to communicate freely with an electroscope; but if they had reason to expect that the disengagement or absorption would be gradual, and of some continuance, they made use of Volta's condenser.

By the action of dilute sulphuric acid upon iron-filings, a violent effervescence was produced, with the evolution of hydrogen gas. After some minutes the electrometer of Volta was found so highly charged, as to be capable of communicating a spark; and the electricity thus produced was of the resinous kind.

By the action of very dilute sulphuric acid upon chalk, a very copious evolution of carbonic acid gas was produced, accompanied by electrical excitation; but not in so eminent a degree as in the former experiment. This electricity also was resinous.

The disengagement of nitrous gas produced a similar result. In order to increase the effect, they combined together the action of six vessels, containing iron-filings, to which they had added dilute nitric acid. The effervescence and production of gas was extremely energetic, and at the same time undoubted indications of resinous electricity were obtained; but as this experiment was made under unfavourable circumstances, the excitement was very feeble.

Three small chafing-dishes insulated, and filled with lighted charcoal, being connected with Volta's condenser, gave such manifest indications of negative electricity, that it would have been easy to have obtained a spark, by increasing the quantity of charcoal employed in the combustion.

It resulted as a natural supposition from these results, that substances in the act of passing into the state of vapour, "carried off electricity," or, as we should phrase it, disturbed the electrical equilibrium between themselves and the surrounding bodies. This appearing conformable to the analogy existing between electricity and heat, they expected that in the vaporization of water negative electricity would be developed. Having arranged four insulated furnaces of hammered iron, so that they should communicate by Lavoisier, La Place, Volta, and Cavallo, with a prospect of obtaining a further elucidation of the matter.

Lavoisier and La Place, *Mém. Acad. Par.* 1781, p. 202; Volta, *Jour. de Physique, Août* 1783, p. 86 and 96; Bennet, *Phil. Trans.* 1787, p. 34; Benedict de Saussure, *Voyages dans les Alpes*, vol. ii. p. 227, edit. 4to. Neufchatel, 1786; Cavallo, *Complete Treatise on Electricity*, vol. iii. p. 270.

§ VI. *Electricity produced by the separation of the particles of bodies.*

(224.) Of the observation of this fact, we are not aware of any earlier instance than the following from Mr. Bennet. "Breaking the glass tear upon a book electrified it negatively, probably by friction in the act of shivering; for when broken in water, it did not electrify it." *Phil. Trans.* 1787, p. 28.

Mr. Wilson states, that if a piece of dry and warm wood be suddenly rent asunder, the two surfaces which have separated become electrified, the one vitreously, the other resinously. The same is remarked of a piece of Muscovy glass, (mica,) and at the same time a flash of light is perceptible in the dark. If a stick of sealing-wax also be broken in two, the surfaces of fracture become vitreously and resinously electrical respectively.

The fracture of the glass tear, or Rupert's drop, has been subsequently examined by Dr. Brewster, in connection with his admirable researches upon light, the origin of which, in this instance, he seems to consider an electrical phenomenon. "Having laid one of these drops upon a table in a dark room, and covered it with a plate of thick glass, to prevent any of the fragments from reaching the eye, the drop was burst by breaking off a part of its tail, and the whole of it appeared luminous; so that at the instant of the fracture, a quantity of faint light, of the same shape and size as the drop itself, was distinctly visible. The same light appeared when these drops were burst under water."

(225.) We are under some doubt whether to refer the experiments of Mr. Wilson, upon the electricity produced by the process of shaving dry wood, to the present section, or to consider this mode of excitation only as a peculiar species of friction. In fact, the same difficulty applies to the whole of this subject. There can be no doubt that in the process of breaking any compact body, a certain kind of friction takes place between the proximate particles at the instant of their separation. Thus, perhaps, the electricity of the split wood, the sealing-wax, and the mica, might be accounted for. In the Rupert's drop, Bennet suspected some such source of excitation, and Dr. Brewster being occupied with a different object of inquiry, does not seem to have examined the electrical state of the powder. Even if no electricity were produced, it is possible that the concussion of the air in contact with the Rupert's drop at the instant of its explosion, might be sufficient to account for the production of light.

Want of space will compel us to pass over the detail of Mr. Wilson's curious experiments; he thus, however, sums up his own result. "From these experiments it appears, that when very dry wood is scraped with a piece of window glass, the shavings are always positively electrified. And if chipped with a knife, the chips are positively electrified if the wood is hot, the edge of the knife not very sharp; and negatively electrified if the wood is quite cold. But if the edge of the knife be very keen, the chips will be negatively electrified, whether the wood is hot or cold.

"The greatest number of trials was made with an insulated knife, which was always electrified contrarily to the chips; but the surface of the wood from which the chips were cut, was very seldom electrified, and when it was, it was always but weakly so, and of the same denomination as that of the weakest of the other two.

It has recently been remarked, that in some waterproof cloths manufactured at Glasgow, where two pieces are cemented together by caoutchouc, dissolved in the impure naphtha which is obtained from the gas works, the adhesion is such that when the two surfaces are torn asunder in the dark, there is a bright flash of electric light, similar to that produced by separating plates of mica, by breaking Rupert's drops, or by breaking sugar candy. Flashes of light also are distinctly produced, by tearing quickly a piece of cotton cloth.

Bennet, *Phil. Trans.* 1787, p. 28; Brewster, *Phil. Trans.* 1815; Wilson, Nicholson's *Jour.* vol. iv. p. 49; Brewster's *Journal*, No. 10, p. 185.

§ VII. *Electricity produced by pressure.*

By pressure.

(226.) With regard to this process for the developement of electricity, we are unable to make any great addition to the few facts which mineralogical writers have brought forward. The following are M. Haüy's remarks upon this subject:

"Chance fortunately so provided, that the first substance in which this property was remarked, is that which, by the energy of its action, claims the first place upon the list. This substance is the transparent variety of carbonate of lime, *Iceland spar*. It possesses in so eminent a degree that property which we may call electrical irritability, that if we take in the one hand a rhomboid of this spar, holding it by two of its opposite edges, at the same time lightly touching two of its parallel planes, by two fingers of the other hand; and then bring it near to the small needle of the electroscope, a decided attraction will be perceptible. If instead of contact, which is but a slight force of the same kind, a more powerful degree of pressure be exerted, the effects produced will be still more remarkable. The electricity evolved by both these methods is vitreous.

"I have remarked, in several substances, the property of becoming electrical by pressure, but as yet the maximum effect has been obtained from Iceland spar. In general the success of the experiments depends upon the degree of purity and transparency of the body operated upon. Those substances especially which are capable of being reduced by mechanical division to plane and smooth laminæ. We may also employ such as have been reduced by art to a similar form. Of substances of the first kind are, topaz, especially the colourless variety, euclase, arragonite, fluate of lime, and carbonate of lead. The fragments of limpid quartz which I have employed, have been polished specimens. All these substances acquire vitreous electricity by friction as by pressure. Sulphate of

PART II.

THEORY OF ELECTRICITY.

INTRODUCTION.

Theory of Electricity.

It has been shown in art. 86. that the phenomena of electricity by *induction*, lead us to the supposition of two electric principles or fluids; each of them consisting of particles which repel those of the same fluid, and attract those of the other. It has been shown also, that this supposition will account for the general phenomena of the collection and *distribution* of electricity, (art. 94. &c.) by the common apparatus. The *discharge*, or instantaneous transmission of one of these fluids from one body to another, has been shown to result (art. 98.) from its accumulation under given circumstances, according to those laws. And the *attractions* and *repulsions* produced by electricity have appeared (art. 17. and 84.) to be the results of the same principles.

The general and obvious character of the phenomena being thus seen to agree with the theory and its consequences, it becomes an object of extreme curiosity and interest to examine whether the quantities, and more complicated circumstances, of the observed effects agree with those which would result by calculation from our assumed principles. If we find this to be the case, and if it appears that whenever the comparison has been made, the laws of the distribution of electricity, and the quantity at each point, coincide, with great exactness, through a remarkable variety of complicated and at first sight anomalous cases, with the results of mathematical investigations founded on this theory, it will be difficult not to believe that the theory truly expresses the laws according to which nature operates. In order, therefore, to bring the evidence of this agreement before the reader, we shall proceed, in the present part, to trace, by analytical investigations, the consequences of the assumed principles, and to compare them with those experiments in which that mode of measurement has been employed which the comparison requires. It may be considered as a circumstance singularly fortunate, with regard to the evidence of the theory, that the experiments on which its reception must principally depend, (those of Coulomb,) were made long before the hypothetical laws with which they were to agree, had been deduced; and, indeed, before those theorems had been discovered, by which they have since been established. The mathematical reasonings on which these deductions are to rest, are of a character extraordinarily artificial and general, and equally remarkable for their beauty and their difficulty. The talents of La Place, of Ivory, and of Poisson, have been requisite to invent the processes which we shall have to follow; and if it be allowed, as we think it cannot be doubted, that in consequence of these investigations, electricity may be considered as an additional physical science brought under the jurisdiction of mathematics, this new province is inferior to no preceding one, not even to physical astronomy, in the refined analysis and elegant theorems in which it abounds. It will be our business to endeavour to introduce this subject in the simplest manner of which it admits, and we shall hope, by breaking it up into propositions, to present it in such a form that every mathematical student, who is familiar with the elements of analysis, may be put in possession of this new branch of mixed mathematics.

Part

Except so far as this labour of simplification is concerned, we shall, in a great measure, follow the admirable Papers of M. Poisson, the first person who succeeded in the investigations which the subject requires. Founding his process on La Place's method of finding the attraction of a spheroid of small eccentricity, which its illustrious author had applied to the determination of the figures of the planets, M. Poisson, in a paper in the *Mém. de l'Instit.* 1811, overcame the principal difficulties of the subject, and solved the case of two conducting spheres in contact, which was one to which many of Coulomb's experiments were referable. In another Memoir in the same volume, he resumed the subject and completed the investigation for the case when the spheres were at any distance, in which the mathematical difficulties which were surmounted were truly remarkable, though, for the sake of brevity and simplicity, we shall be compelled to omit this part of his calculations.

For the purpose of laying before the reader a comparison of the results of these investigations with experiments, we shall adopt the following arrangement.

Chap. I. On the mode of measuring electricity.
Chap. II. On the mathematical theory of the distribution of electricity compared with experiment.

CHAPTER I.

On the mode of measuring electricity.

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(228.) In art. 56. we have described the *electrical balance of Coulomb*, as an instrument by means of which we may measure the intensity of the repulsive or attractive forces which small electrified bodies exert upon each other. That we may be enabled to deduce accurate results from the experiments which we shall have to describe, we shall now obtain the formula by which the intensity of the force is determined.

It will be recollected, that in this instrument a small horizontal bar, B D, fig. 45, is suspended by a slender filament from its centre C. When this bar is horizontally moved round the centre C from its quiescent position, the tendency to return to that position is the torsion of the filament by which it hangs; and it is found that the force of this torsion is very accurately as the angle through which B D has deviated, and that this law continues true for a whole circumference. The bar B D carries a small ball D, which, being electrified, is repelled by a fixed ball at E, similarly electrified. The position in which B D rests, will determine the intensity of the repulsion between E and D. The same is true of the attraction of two balls dissimilarly electrified.

The upper end of the filament C is fastened to a button which can be turned round, and by this means the quiescent position of B D can be changed; and this button carries an index, which indicates the place of this quiescent position upon a graduated circle. Let C A be the quiescent position of C D when not repelled.

It will appear from experiment, that the attractive or repulsive force of electricity varies inversely as the square of the distance of the attracting or repelling points. Hence, if F be the force which two such points exert upon one another at a distance equal to unity, their force of repulsion at a rectilinear distance D, will be $\frac{\mathrm{F}}{\mathrm{D}^2}$. And conversely, if, having represented the force by $\frac{\mathrm{F}}{\mathrm{D}^2}$, and measured it for different values of D, it appears that F is constant; it will follow that the assumed law is the true one, and that the law of the attraction and repulsion is, that they vary inversely as the square of the distance.

(229.) Let E and D, fig. 91, be considered as points; $\mathrm{DE} = \mathrm{D}$; force of repulsion $= \frac{\mathrm{F}}{\mathrm{D}^2}$. Let this force, which acts in the direction E D, be resolved into two in the directions C D and T D, T D being a tangent at D to the circle A E D. The latter of these only is balanced by the torsion. And by the laws of statics it will be equal to $\frac{\mathrm{F}}{\mathrm{D}^2} \cos \mathrm{EDT}$. Let $\mathrm{ECD} = a$; and $\mathrm{EDT} = \mathrm{EBD} = \frac{1}{2}\mathrm{ECD} = \frac{1}{2}a$. Hence the force which balances the torsion is $\frac{\mathrm{F}}{\mathrm{D}^2} \cos \frac{1}{2} a$.

Let $\mathrm{CD} = r$, and we obviously have $\mathrm{D} = \mathrm{ED} = 2 r \sin \frac{1}{2} a$. Hence the force of torsion is $\frac{\mathrm{F} \cos \frac{1}{2} a}{4 r^2 \sin^2 \frac{1}{2} a}$.

Chap. I.

Let now A C D, the angle of torsion, = A. The force of torsion is proportional to this angle, and may be represented by n A, n being constant for the same filament. And this force may be considered as acting in the direction D T, and producing an equilibrium with the force first found. Hence

$$\frac{\mathrm{F} \cos \frac{1}{2} a}{4 r^2 \sin^2 \frac{1}{2} a} = n \mathrm{A};$$

and

$$\frac{\mathrm{F}}{4 n r^2} = \mathrm{A} \sin \tfrac{1}{2} a \tan \tfrac{1}{2} a.$$

Hence, so long as we use the same apparatus, the force of repulsion, at a given distance, is as $\mathrm{A} \sin \frac{1}{2} a \tan \frac{1}{2} a$.

By moving the button, we alter the position of the point A, and consequently we alter the angle A. By this means the position of C D, and the angle a will also vary, and we may thus examine the magnitude of the force at different distances.

(230.) The following experiment of Coulomb will exemplify the mode of applying the machine, and will also prove the law of repulsion which has been mentioned.

After the balls E and D were electrified, they separated so that the arc E D was 36°.

He then turned the index C A in the direction D E, so as to make the arc C D 18°; and for this purpose it was necessary to turn C A through 126°.

He afterwards turned the index C A in the direction D E, till the arc E D was 8½°, and this was done by moving C A through 567° from its first position.

It is manifest that the angle of torsion A is equal to A E + E D: hence we have

Values of a	Values of A
36°	36°
18°	144°
8½°	575½°

If we suppose the values of a to represent the distances, (which they do nearly, because the arcs are small, and therefore nearly as their chords,) it will appear that while the distances are nearly as 1, ½, ¼, the angles of torsion, and therefore the forces, are as 1, 4, 16; that is, the forces are inversely as the squares of the distances.

(231.) To examine this result more accurately, we shall apply the formula of art. 229. We shall thus have by calculating the values of $\mathrm{A} \sin \frac{1}{2} a \tan \frac{1}{2} a$.

Experiments.	a	A	$\mathrm{A} \sin \frac{1}{2} a \tan \frac{1}{2} a$.
First........	36	36	3.614
Second......	18	144	3.568
Third	8½	575½	3.169
Suppose	9	576	3.557

The last column should be constant, in order to prove the law to be such as we have supposed it. It may be seen that the numbers are very nearly equal. The deviation of the last corresponds, as it appears,

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to an error of about half a degree in observation. Though this is not a greater error than may be conceived to be committed, it is more probable that it is only apparent, and that it arises from the too great proximity of the two balls. It will be seen hereafter, that this proximity introduces a mutual action of the fluids on the surface of the two spheres, which gives rise to new circumstances, and makes the action of spheres different from that of points.

Neglecting therefore this small discrepancy, which is perhaps rather a confirmation of the exactitude of the observations, we may consider these results as establishing the truth of the law which we have mentioned, that electrical forces vary inversely as the square of the distance.

(232.) The filament used by Coulomb in this experiment, was a silver wire of extreme fineness. Its length was twenty-eight inches, and one foot of it weighed only $\frac{1}{16}$th of a grain. It was found that to twist it through a whole circumference, the force to be applied perpendicularly at the extremity of the bar C D was $\frac{1}{340}$th of a grain; and since the forces of torsion are as the angles of torsion, it follows from this, that to twist it through one degree, a force of $\frac{1}{122400}$th of a grain was sufficient; so that the slightest repulsive force between the two balls caused them to separate.

This thread, in consequence of its excessive tenuity, broke with the smallest agitation; and in succeeding experiments Coulomb found it more convenient to use one of nearly twice the diameter, though its flexibility for an equal length was necessarily sixteen times less.

Previously to making use of such a thread, it is advisable to keep it, for two or three days, stretched by a weight equal to about half of what it can sustain without breaking. We must also avoid twisting it through a greater angle than 300°; for beyond this limit it is liable to receive a *wrench*, in which case it no longer reacts with perfect elasticity.

(233.) The laws of electrical attraction may be determined in the same manner, and by means of the same apparatus as those of repulsion. In this case it is requisite that the balls should not touch each other originally, and it is convenient to fasten a fine thread of silk in a vertical position in the instrument, so as to prevent the bar C D from coming to E. The quiescent position of the bar C A, must, in this case, be on the other side of C D; and if it is found that the attraction of the fixed ball E is so great as to bring D up to the thread just mentioned, the torsion must be increased by turning the index which moves C A, in the direction E D, till we find a position where the equilibrium subsists.

(234.) Coulomb likewise determined the law of electrical attraction by another process of the following kind. A needle, of which the extremity only was electrified, was suspended horizontally at a certain distance from a globe charged with the opposite electricity. This needle, when disturbed, oscillated in consequence of the attraction of the globe; and from the number of oscillations which it performed in a given time, he determined the attractive force, in exactly the same manner as when we determine the force of terrestrial gravity from the oscillations of a common pendulum.

The needle was a slender stick of gum-lac of fifteen or sixteen lines in length, suspended by a single filament of silk, and carrying on one of its extremities a small circle of gilt paper. The globe was of wood, a foot in diameter, covered with tin-foil, and supported by three slender tubes of gum-lac. The torsion of the filament of silk would be insensible for the angle of oscillation; and the variation of the distance and position of the end of the needle from the globe during the oscillation was also too small to affect the result. The action of the whole surface of the globe would be the same as if the attractive or repulsive energy were all collected in the centre. Hence we may apply immediately the principles on which we calculate the oscillation of a pendulum by gravity. Therefore the force will be inversely as the square of the time of an oscillation; or directly as the square of the number of oscillations in a given time. And if the force be inversely as the square of the distance, the times of oscillation will be as the distances of the needle from the centre of the globe. The following were the results of experiment:

Distances of the circle of gilt paper from the centre of the globe.	Duration of fifteen oscillations.
9	20″
18	41
24	60

The times are nearly proportional to the distances. The former are as 20, 40, 54, and the latter as 20, 41, 60. The deviation of the last time from its proper value, is to be attributed principally to the last observation having been made four minutes after the first, in consequence of which the electrical force had become smaller than it was at first, as will be immediately explained.

(235.) In art. 66. it has been mentioned as a result of Coulomb's observations, that in a given state of the atmosphere the dissipation in any given short time varies as the charge. This law was established, as has been stated, by experiments made with the torsion balance. Two balls, similarly electrified, repelled each other in such a manner that they were kept in equilibrium at a distance of 20° by a torsion of 160°. After three minutes they approached nearer, and in order to restore them to the distance of 20°, it was requisite to untwist the thread by turning the index through 30°, so that the torsion was 130°. Hence it appeared that in this case the diminution of electrical intensity was 30° in 3′, or 10° in 1′. Also the mean torsion between 130° and 160° is 145°; and hence the loss of electricity on the day of this experiment was $\frac{1}{14.5}$ per minute. Similar experiments were made with other degrees of torsion, and at other times, and the result was what has been mentioned.

From the law just stated we can, in such a case as the above, calculate the intensity of the electric forces after the lapse of any given time.

Let A be the angle of torsion after any time t. Then for a given small time the decrement of A is proportional to A; or, taking the differentials, $-dA$ is proportional to A. Also for small times this decrement is proportional to the time, that is $-dA$ is proportional to dt. Hence $-dA$ is as $A\,dt$. Let a be a constant quantity, such that

$$-dA = aA\,dt$$

$$\therefore -\frac{dA}{A} = a\,dt;\ l\frac{A_0}{A} = at.$$

A_0 being the torsion when $t = 0$, and l the Napierian logarithm.

If the loss of electricity be $\frac{1}{n}$ in one minute, we shall have, making $t = 1$, $A = A_0\left(1 \quad \frac{1}{n}\right)$

$$\therefore l \frac{1}{1 - \frac{1}{n}} = a \text{ ; and if } n \text{ be considerable,}$$

$$\frac{1}{n} = a\text{, nearly.}$$

Hence a may be taken to be the fraction which expresses the loss of electricity in 1′.

If M be the Napierian logarithm of 10; log, the common logarithm, we have

$$M\,(\log A_0 - \log A) = a\,t;\ \log A = \log A_0 - \frac{a\,t}{M}.$$

(236.) The following example may illustrate the application of the above formulas.

On a certain day it was found that the primitive torsion (A_0) was 150°, and the diminution $\frac{1}{41}$ per minute. It is required to find the torsion (A) at an observation made 45 minutes after the first.

$$A_0 = 150,\ a = \frac{1}{41},\ t = 45,\ M = 2.302585;$$

$$\frac{a}{M} = \frac{1}{41 \times 2.302585} = 0.010595;\ \frac{a\,t}{M} = 0.4766625;$$

$$\log A_0 = 2.1760913 \therefore \log A = 1.6994288;$$

$$\text{whence} \qquad A = 50^\circ\ 3'\ 10''.$$

The value given by observation was $A = 50^\circ\ 0'\ 0''$, which may be considered as an absolute coincidence with calculation, since it is hardly possible in such experiments to be accurate to fractions of a degree.

If we had other observations on the same day to calculate, the same value of $\frac{a}{M}$ would answer for all.

The law of the decrease of the torsion being thus established, it is easily seen that when the balls are equal, the force of each decreases according to the same law. And if the balls be in any ratio of inequality, the decrement of their joint action will still follow the same proportion; which is found to be confirmed by experiment.

By means of calculations founded upon the formulas just given, we can make allowance for the continual dissipation of electricity; and we may thus use the observations and measures which are taken with respect to the same body at successive times, in the same manner as if they were all taken at the same time, or as if the electrical state of the body did not undergo any change.

CHAPTER II.

On the mathematical theory of the distribution of electricity compared with experiment.

(237.) In articles 82. 83. 84. 85. 86. have been given the general reasons from which we infer the existence of two electric fluids, each consisting of particles which repel each other, and which attract those of the other fluid. The forces of attraction and repulsion are inversely as the squares of the distances, and at equal distances the attractive and repulsive forces are equal. We have also seen that the separated electricity, in any conducting body, arranges itself contiguous to the surface, so that no portion of the uncombined or active fluids remains in the interior of the body. From these principles it follows, that when two conducting bodies, containing any charges of electricity, are within the sphere of each other's sensible influence, the distribution of electricity in them will be regulated by laws depending upon the mutual action of the fluids. These laws may in some cases be deduced by mathematical processes, and their results compared with facts, by means of the methods, given in the preceding chapter, of measuring the electricity at any point of a conductor.

We shall give these mathematical processes, and their comparison with experiment, for the case of two spheres which act upon one another. We shall, in the first place, have to determine the attraction or repulsion of a stratum of fluid, distributed at the surface of a sphere, with its thickness varying according to any law; and we shall then have to determine, from the forces thus obtained, the variation of the thickness of the stratum upon each sphere, in order that the fluids may be in equilibrium by their mutual action. The agreement of the disposition, thus determined by theory, with that given by observation, will be shown in each case when the calculations have been executed.

The principle on which these calculations rest is this, that for the existence of a permanent state of electrical equilibrium, it is requisite that the stratum of fluid on the surface of the conductors should not exercise any attraction on any of the points in the interior of those bodies. If it do so, its action will decompose the combined electricity of the bodies, and the separated electricity will proceed to the surface of the bodies, and will require new conditions for its equilibrium.

§ I. *Attraction of a stratum of fluid on the surface of a sphere.*

(238.) *To find the attraction of any body, the particles of which attract with forces which are inversely as the square of the distance.*

Let a, b, c be the rectangular coordinates of the point attracted; x, y, z the coordinates of any point of the attracting body; $d\,m$ the differential of the body corresponding to that point. Then the distance of these two points is $\sqrt{\{(a - x)^2 + (b - y)^2 + (c - z)^2\}}$ and the attraction in the direction of this distance is as

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$\frac{d\,m}{(a-x)^2+(b-y)^2+(c-z)^2}$. And if this be resolved in the direction of x, it must be multiplied by $\frac{a-x}{\sqrt{\{(a-x)^2+(b-y)^2+(c-z)^2\}}}$. Whence it will become $\frac{(a-x)\,d\,m}{\{(a-x)^2+(b-y)^2+(c-z)^2\}^{\frac{3}{2}}}$. And the integral of this for the whole mass of the body will be the whole attraction. Hence attraction in direction of $x = \int \frac{(a-x)\,d\,m}{\{(a-x)^2+(b-y)^2+(c-z)^2\}^{\frac{3}{2}}}$.

Let
$$\mathrm{V} = \int \frac{d\,m}{\sqrt{\{(a-x)^2+(b-y)^2+(c-z)^2\}}}$$
which is the sum of each particle divided by its distance from the attracted point. Then differentiating with respect to a, observing that $d\,m$ does not depend on a;

$$-\left(\frac{d\,\mathrm{V}}{d\,a}\right) = \int \frac{(a-x)\,d\,m}{\{(a-x)^2+(b-y)^2+(c-z)^2\}^{\frac{3}{2}}}$$
$$= \text{attraction in direction } a.$$

Similarly
$$-\left(\frac{d\,\mathrm{V}}{d\,b}\right) = \text{attraction in direction } b.$$
$$-\left(\frac{d\,\mathrm{V}}{d\,c}\right) = \text{attraction in direction } c.$$

In this case a, b, c may be measured in any directions whatever; and if f be the distance of the differential particle $d\,m$ from the attracted particle
$$\mathrm{V} = \int \frac{d\,m}{f}.$$

(239.) We have now to find the quantity V; this we shall do by expanding it into a series, the coefficients of which have peculiar properties, depending upon a partial differential equation to which they are subject. As these properties are connected with very curious analytical investigations, and introduce into this and other problems a simplicity and generality truly remarkable, it will be convenient to refer to them by name; and we shall therefore distinguish them by that of their illustrious inventor, calling the differential equation and the coefficients in question, *Laplace's equation*, and *Laplace's coefficients.*

Mr. Ivory, in the *Phil. Trans.* for 1812, has given the same method of finding the attractions of spheroids, with admirable simplicity and clearness. After pointing out a want of generality in the reasonings of Laplace, in one part of his formulas, Mr. Ivory has given an equation, which is of great service in performing the requisite integrations in a satisfactory manner: we shall have occasion to use this, and we shall call it *Ivory's equation.*

(240.) *To deduce Laplace's equation.*

Let f be the distance of the particle attracted from the attracting particle, $d\,s'$ the differential of the attracting surface, and y' the thickness of the stratum, at any point. Then $\mathrm{V} = \int \frac{y'\,d\,s'}{f}$.

Let r' be the distance from the centre of the attracting particle $y'\,d\,s'$, r that of the point attracted, and γ the cosine of the angle between them. Then $f = \sqrt{(r^2 + r'^2 - 2\,r\,r'\,\gamma)}$.

Take a fixed line drawn from the centre of the sphere, and let θ be the angle which r makes with this line. Also let the plane in which θ is, make an angle ω with a fixed plane. Then the coordinates ω, θ, r determine the attracted point. Let ω', θ', r' be the corresponding coordinates for the attracting point, and we shall have, by spherics, making $\cos\theta = \mu$, $\cos\theta' = \mu'$;
$$\gamma = \mu\,\mu' + \sqrt{1-\mu^2}\,\sqrt{1-\mu'^2}\cos(\omega - \omega').$$

We have now to prove that if $\frac{1}{f} = u$

$$\frac{r\,d^2.\,r\,u}{d\,r^2} + \frac{d\,.\,(1-\mu^2)\frac{d\,u}{d\,\mu}}{d\,\mu} + \frac{1}{1-\mu^2}\,\frac{d^2\,u}{d\,\omega^2} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(\mathrm{A})$$

Whence it follows, since $\mathrm{V} = \int u\,y'\,d\,m'$, and y', $d\,m'$ are independent of r, ω, μ, that

$$\frac{r\,d^2.\,r\,\mathrm{V}}{d\,r^2} + \frac{d\,.\,(1-\mu^2)\,\frac{d\,\mathrm{V}}{d\,\mu}}{d\,\mu} + \frac{1}{1-\mu^2}\,\frac{d^2\,\mathrm{V}}{d\,\mu^2} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(\mathrm{B})$$

To prove equation (A), let $k = f^2 = r^2 + r^2 - 2\,r\,r'\,\gamma$;
$$\therefore k = r^2 + r'^2 - 2\,r\,r'\,(\mu\,\mu + \sqrt{1-\mu^2}\,\sqrt{1-\mu'^2}\cos(\omega - \omega'));$$

$$\frac{d\,u}{d\,r} = \frac{d\,.\,\dfrac{1}{k^{\frac{1}{2}}}}{d\,r} = -\frac{1}{2\,k^{\frac{3}{2}}}\,\frac{d\,k}{d\,r} = -\frac{r - r'\,\gamma}{k^{\frac{3}{2}}};$$

$$\frac{d\,.\,r\,u}{d\,r} = \frac{r\,d\,u}{d\,r} + u = -\frac{r^2 - r\,r'\,\gamma}{k^{\frac{3}{2}}} + \frac{1}{k^{\frac{1}{2}}};$$

$$\frac{d^2\,.\,r\,u}{d\,r^2} = \frac{3\,r\,(r - r'.\gamma)^2}{k^{\frac{5}{2}}} - \frac{2\,r - r'\,\gamma}{k^{\frac{3}{2}}} - \frac{r - r'\,\gamma}{k^{\frac{3}{2}}};$$

$$= \frac{3\,r\,r'^2\,(\gamma^2 - 1)}{k^{\frac{5}{2}}} + \frac{2\,r'\,\gamma}{k^{\frac{3}{2}}};$$

$$\therefore \frac{r\,d^2\,.\,r\,u}{d\,r^2} = \frac{3\,r^2\,r'^2\,(\gamma^2 - 1)}{k^{\frac{5}{2}}} + \frac{2\,r\,r'\,\gamma}{k^{\frac{3}{2}}}.$$

Again,

$$\frac{d\,u}{d\,\mu} = -\frac{1}{2\,k^{\frac{3}{2}}}\,\frac{d\,k}{d\,\mu},\ \frac{d^2\,u}{d\,\mu^2} = \frac{3}{4\,k^{\frac{5}{2}}}\,\frac{d\,k^2}{d\,\mu^2} - \frac{1}{2\,k^{\frac{3}{2}}}\,\frac{d^2\,k}{d\,\mu^2};$$

$$\frac{d\,.(1 - \mu^2)\,\dfrac{d\,u}{d\,\mu}}{d\,\mu} = (1 - \mu^2)\left\{\frac{3}{4\,k^{\frac{5}{2}}}\,\frac{d\,k^2}{d\,\mu^2} - \frac{1}{2\,k^{\frac{3}{2}}}\,\frac{d^2\,k}{d\,\mu^2}\right\} + \frac{\mu}{k^{\frac{3}{2}}}\,\frac{d\,k}{d\,\mu}.$$

Also

$$\frac{d\,u}{d\,\omega} = -\frac{1}{2\,k^{\frac{3}{2}}}\,\frac{d\,k}{d\,\omega},\ \frac{d^2\,\omega}{d\,\omega^2} = \frac{3}{4\,k^{\frac{5}{2}}}\,\frac{d\,k^2}{d\,\omega^2} - \frac{1}{2\,k^{\frac{3}{2}}}\,\frac{d^2\,k}{d\,\omega^2};$$

$$\therefore \frac{d\,.\,(1 - \mu^2)\,\dfrac{d\,u}{d\,\mu}}{d\,\mu} + \frac{1}{1 - \mu^2}\,\frac{d^2\,k}{d\,\omega^2} =$$

$$\frac{3}{4\,k^{\frac{5}{2}}}\left\{(1 - \mu^2)\,\frac{d\,k^2}{d\,\mu^2} + \frac{1}{1 - \mu^2}\,\frac{d\,k^2}{d\,\omega^2}\right\} - \frac{1}{2\,k^{\frac{3}{2}}}\left\{(1 - \mu^2)\,\frac{d^2\,k}{d\,\mu^2} + \frac{1}{1 - \mu^2}\,\frac{d^2\,k}{d\,\omega^2}\right\} + \frac{\mu}{k^{\frac{3}{2}}}\,\frac{d\,k}{d\,\mu}.$$

Now

$$\frac{d\,k}{d\,\mu} = -2\,r\,r'\left\{\mu' - \frac{\sqrt{1 - \mu'^2}}{\sqrt{1 - \mu^2}}\,\mu\cos(\omega - \omega')\right\};$$

$$\frac{d\,k}{d\,\omega}\,. = 2\,r\,r'\,\sqrt{1 - \mu^2}\,\sqrt{1 - \mu'^2}\,\sin(\omega - \omega');$$

hence,

$$(1 - \mu^2)\,\frac{d\,k^2}{d\,\mu^2} + \frac{1}{1 - \mu^2}\,\frac{d\,k^2}{d\,\omega^2} = 4\,r^2\,r'^2\left\{\begin{matrix}1 - \mu^2\,\mu'^2 - (1 - \mu^2)\,(1 - \mu'^2)\cos^2(\omega - \omega') \\ - 2\,\mu\,\mu'\,\sqrt{1 - \mu^2}\,\sqrt{1 - \mu'^2}\cos(\omega - \omega')\end{matrix}\right\}$$

$$= 4\,r^2\,r'^2\,\{1 - \gamma^2\}$$

Also,

$$\frac{d^2\,k}{d\,\mu^2} = \frac{2\,r\,r'}{1 - \mu^2}\,\frac{\sqrt{1 - \mu'}}{\sqrt{1 - \mu^2}}\cos(\omega - \omega');$$

$$\frac{d^2\,k}{d\,\omega^2} = 2\,r\,r'\,\sqrt{1 - \mu^2}\,\sqrt{1 - u'^2}\cos(\omega - \omega').$$

Hence

$$(1 - \mu^2)\,\frac{d^2\,k}{d\,\mu^2} + \frac{1}{1 - \mu^2}\,\frac{d^2\,k}{d\,\omega^2} = 4\,r\,r'\,\frac{\sqrt{1 - \mu'^2}}{\sqrt{1 - \mu^2}}\cos(\omega - \omega').$$

Again,

$$\frac{\mu}{k^{\frac{3}{2}}}\,\frac{d\,k}{d\,\mu} = \frac{2\,r\,r'}{k^{\frac{3}{2}}}\left\{\frac{\sqrt{1 - \mu'^2}}{\sqrt{1 - \mu^2}}\,\mu^2\cos(\omega - \omega') - \mu\,\mu'\right\}.$$

Hence the expression $\dfrac{d\,(1 - \mu^2)\,\dfrac{d\,u}{d\,\mu}}{d\,\mu} + \dfrac{1}{1 - \mu^2}\,\dfrac{d^2\,k}{d\,\omega^2}$ becomes

$$\frac{3\,r^2\,r'^2}{k^{\frac{5}{2}}}(1-\gamma^2) - \frac{2\,r\,r'}{k^{\frac{3}{2}}}\left\{\sqrt{1-\mu^2}\,\sqrt{1-\mu'^2}\cos(\omega-\omega') + \mu\,\mu'\right\};$$

$$= \frac{3\,r^2\,r'^2}{k^{\frac{5}{2}}}(1-\gamma^2) - \frac{2\,r\,r'\,\gamma}{k^{\frac{3}{2}}}$$

Hence we have $$r\,\frac{d^2 . r\,u}{d\,r^2} + \frac{d\,(1-u^2)\dfrac{d\,u}{d\,\mu}}{d\,\mu} + \frac{1}{1-\mu^2}\frac{d^2\,u}{d\,\omega^2} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (A)$$

Whence $$r\,\frac{d^2\,r\,V}{d\,r^2} + \frac{d\,(1-\mu^2)\dfrac{d^2\,V}{d\,\mu}}{d\,\mu} + \frac{1}{1-\mu^2}\,\frac{d^2\,V}{d\,\omega^2} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (B)$$

which is the general equation.

(241.) Let $\dfrac{1}{\sqrt{(r^2 - 2\,r\,r'\,\gamma + r'^2)}} = \dfrac{1}{r}\,U_0 + \dfrac{r'}{r^2}\,U_1 + \dfrac{r'^2}{r^3}\,U_2 + \ldots + \dfrac{r'^n}{r^{n+1}}\,U_n + \ldots$

When U_n is a rational function of n dimensions in γ.

And the equation (A), being true of u, is true of this series. Hence, substituting and equating the coefficients of $\dfrac{r'^n}{r^{n+1}}$ we have

$$n\,(n+1)\,U_n + \frac{d\,.\,(1-\mu^2)\,\dfrac{d\,U_n}{d\,\mu}}{d\,\mu} + \frac{1}{1-\mu^2}\,\frac{d^2\,U_n}{d\,\omega^2} = 0 \ldots\ldots\ldots\ldots\ldots\ldots (L)$$

which is *Laplace's equation.* And the coefficients U_0, U_1, &c. subject to this equation are *Laplace's coefficients.*

It may be observed that U_n will involve μ, μ', and ω, ω' similarly.

(242.) *To deduce Ivory's equation.*

Let $$S = \frac{1}{f^{2m+1}};\ \text{then since } f = \sqrt{(r^2 - 2\,r\,r'\,\gamma + r'^2)}$$

$$\frac{d\,S}{d\,r} = -\,(2\,m+1)\,\frac{r-\gamma\,r'}{f^{2m+3}};\quad \frac{d\,S}{d\,\gamma} = (2\,m+1)\,\frac{r\,r'}{f^{2m+3}};$$

$$\frac{d^2\,S}{d\,r\,d\,r'} = (2\,m+1)\ \frac{(2\,m+3)\,(r-\gamma\,r')\,(r'-\gamma\,r) + \gamma\,f^2}{f^{2m+5}};$$

$$\frac{d\,.\,(1-\gamma^2)^{m+1}\,\dfrac{d\,S}{d\,\gamma}}{d\,\gamma} = (2\,m+1)\,(1-\gamma^2)^m\,r\,r'\ \frac{(2\,m+3)\,(1-\gamma^2)\,r\,r' - (2\,m+2)\,\gamma\,f^2}{f^{2m+5}};$$

and by substituting for f^2 its value, it will be seen that the two fractions are equal,

hence $$r\,r'\,(1-\gamma^2)^m\,\frac{d^2\,S}{d\,r\,d\,r'} - \frac{d\,.\,(1-\gamma^2)^{m+1}\,\dfrac{d\,S}{d\,\gamma}}{d\,\gamma} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (C)$$

We have $$\frac{1}{f} = \frac{1}{r}\,U_0 + \frac{r'}{r^2}\,U_1 + \ldots + \frac{r'^n}{r^{n+1}}\,U_{n+1} + \ldots$$

Differentiate m times in succession with respect to γ, observing that $\dfrac{d\,f}{d\,\gamma} = -\dfrac{r\,r'}{f}$: and we have

$$\frac{1}{f^{2m+1}} = \frac{1}{1\,.\,3\,.\,5\ldots 2\,m-1}\left\{\frac{1}{r^{2m+1}}\,\frac{d^m\,U_m}{d\,\gamma^m} + \frac{r'}{r^{2m+2}}\,\frac{d^m\,U_{m+1}}{d\,\gamma^m} + \ldots + \frac{r'^{n-m}}{r'^{n+m+1}}\,\frac{d^m\,U_n}{d\,\gamma^{m+\ldots}}\right\}$$

Substitute this series for S in (C), and equate terms involving $\dfrac{r'^{n-m}}{r^{n+m+1}}$, and we have

$$(n-m)\,(n+m+1)\,(1-\gamma^2)^m\,\frac{d^m\,U_n}{d\,\gamma^m} + \frac{d\,.\,(1-\gamma^2)^{m+1}\,\dfrac{d^{m+1}\,U_n}{d\,\gamma^{m+1}}}{d\,\gamma} = 0 \ldots\ldots\ldots\ldots\ldots\ldots (I)$$

which is *Ivory's equation.*

(243.) *To expand* U_n *in terms of* γ.

The following equation might be deduced independently, but it is included in *Ivory's equation* of making $m = 0$,

$$n(n+1)\,U_n + \frac{d\,.\,(1-\gamma^2)\dfrac{d\,U_n}{d\,\gamma}}{d\,\gamma} = 0 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (D)$$

Now let $U_n = N\,\gamma^n + N^{(1)}\,\gamma^{n-1} + N^{(2)}\,\gamma^{n-2} + \ldots + N^{(m)}\,\gamma^{n-m} + \ldots$ which, it will be recollected, is the form of U_n; and by performing the operations indicated in equation (D) we shall find $N^{(1)} = 0$, $N^{(3)} = 0$, &c. for all the odd powers, and

$$N^{(2m)} = -\frac{(n-2m+2)\,(n-2m+1)}{2m\,(2n-2m+1)}\,N^{(2m-2)}$$

whence putting $m = 1$, $m = 2$, &c. we find all the coefficients in succession in terms of the first. We have thus

$$U_n = N\left(\gamma^n - \frac{n\,(n-1)}{2\,(2n-1)}\,\gamma^{n-2} + \frac{n\,(n-1)\,(n-2)\,(n-3)}{2\,.\,4\,(2n-1)\,(2n-3)}\,\gamma^{n-4} - \&c.\right)$$

In order to find N, it is to be observed that U_n is the coefficient of $\frac{r'^n}{r^{n+1}}$ in the expansion of $\frac{1}{f}$. Now $\frac{1}{f} = \frac{1}{\sqrt{(r^2+r'^2)}}\left\{1 - \frac{2\,\gamma\,r\,r'}{r^2+r'^2}\right\}^{-\frac{1}{2}}$: and, by the binomial theorem, the term containing γ^n will be

$$\frac{1\,.\,3\,.\,5\,..\,(2n-1)}{1\,.\,2\,.\,3\,\ldots\ldots\,n}\;\frac{\gamma^n\,r^n\,r'^n}{(r^2+r'^2)^{n+\frac{1}{2}}}$$

$$= \frac{1\,.\,3\,.\,5\,..\,(2n-1)}{1\,.\,2\,.\,3\,\ldots\ldots\,n}\left\{\frac{\gamma^n\,r'^n}{r^{n+1}} + \&c.\right\}$$

Whence it is clear that $\qquad N = \frac{1\,.\,3\,.\,5\,\ldots\,(2n-1)}{1\,.\,2\,.\,3\,\ldots\ldots\,n}$. Hence

$$U_n = \frac{1\,.\,3\,.\,5\ldots\ldots(2n-1)}{1\,.\,2\,.\,3\ldots\ldots\ldots\,n}\left\{\gamma^n - \frac{n\,.\,(n-1)}{2\,(2n-1)}\,\gamma^{n-2} + \frac{n\,(n-1)\,(n-2)\,(n-3)}{2\,.\,4\,(2n-1)\,(2n-3)}\,\gamma^{n-4} + \&c.\right\}$$

(244.) *To expand* U_n *in terms of* $\omega - \omega'$.

If we make $\omega - \omega' = \phi$, since $\gamma = \mu\,\mu' + \sqrt{(1-\mu^2)}\,\sqrt{(1-\mu'^2)}\cos\phi$, it is easy to see that U_n may be expanded in terms involving successively $\cos\phi$, $\cos 2\,\phi$, $\cos 3\,\phi$, &c.; and our object is to find the coefficients of these terms. Also it is clear that the term which involves $\cos m\,\phi$ will involve $(1-\mu^2)^{\frac{m}{2}}$ Hence let

$$U_n = H^{(0)} + H^{(1)}\,(1-\mu^2)^{\frac{1}{2}}\cos\phi + H^{(2)}\,(1-\mu^2)^{\frac{2}{2}}\cos 2\,\phi + \ldots + H^{(m)}\,(1-\mu^2)^{\frac{m}{2}}\cos m\,\phi + \ldots\ldots$$

Now substitute this series for U_n in Laplace's equation (L), and we shall find, by equating coefficients of $\cos m\,\phi$,

$$(n-m)\,(n+m+1)\,(1-\mu^2)^{\frac{m}{2}}\,H^{(m)} - 2\,(m+1)\,\mu\,(1-\mu^2)^{\frac{m}{2}}\,\frac{d\,H^{(m)}}{d\,\mu} + (1-\mu^2)^{\frac{m}{2}+1}\,\frac{d^2\,H^{(m)}}{d\,\mu^2} = 0.$$

And if we multiply this by $(1-\mu^2)^{\frac{m}{2}}$, we shall have

$$(n-m)\,(n+m+1)\,(1-\mu^2)^m\,H^{(m)} - 2\,(m+1)\,\mu\,(1-\mu^2)^m\,\frac{d\,H^{(m)}}{d\,\mu} + (1-\mu^2)^{m+1}\,\frac{d^2\,H^{(m)}}{d\,\mu^2} = 0,$$

which is equivalent to

$$(n-m)\,(n+m+1)\,(1-\mu^2)^m\,H^{(m)} + \frac{d\,.\,(1-\mu^2)^{m+1}\dfrac{d\,H^{(m)}}{d\,\mu}}{d\,\mu} = 0 \ldots\ldots\ldots$$

This agrees with Ivory's equation (I), if we make $H^{(m)} = \frac{d^m\,U_n}{d\,\gamma^m}$, and then put μ for γ. Hence $H^{(m)}$ will be found by knowing U_n. The value of N, (art. 243.) being indeterminate in this case, we have

$$H^{(m)} = B^{(m)}\,\frac{d^m\,U_n}{d\,\gamma^m},$$

when $B^{(m)}$ is a coefficient independent of μ.

Let Q_n represent the same function of μ which U_n is of γ,

or

$$Q_n = \frac{1\,.\,3\,.\,5\,\ldots\,2n-1}{1\,.\,2\,.\,3\ldots\ldots\,n}\left\{\mu^n - \frac{n\,(n-1)}{2\,(2n-1)}\,\mu^{n-2} + \&c.\right\}$$

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then we shall have for the term of U_n, involving $\cos m\,\phi$,

$$B^{(m)}\frac{d^m Q_n}{d\,\mu^m}(1-\mu^2)^{\frac{m}{2}}\cos m\,\phi;$$

in which $B^{(m)}$ does not involve μ. But μ and μ' enter alike into the expression of Q_n; and hence they will appear similarly in every term of the expansion. Hence we shall have for the term involving $\cos m\,\phi$

$$\beta^{(m)}\frac{d^m Q_n}{d\,\mu^n}\cdot\frac{d^m Q'_n}{d\,\mu'^n}(1-\mu^2)^{\frac{m}{2}}(1-\mu'^2)^{\frac{m}{2}}\cos m\,\phi,$$

when $\beta^{(m)}$ is independent both of μ and μ', and Q' is the same function of μ' that Q is of μ.

Hence $$U_n=\beta^{(0)}\,Q_n\,Q'_n+\beta^{(1)}\,(1-\mu^2)^{\frac{1}{2}}\,(1-\mu'^2)^{\frac{1}{2}}\,\frac{d\,Q_n}{d\,\mu}\,\frac{d\,Q'_n}{d\,\mu}\cos\phi$$
$$+\beta^{(2)}\,(1-\mu^2)^{\frac{2}{2}}\,(1-\mu'^2)^{\frac{2}{2}}\,\frac{d^2\,Q_n}{d\,\mu^2}\cdot\frac{d^2\,Q'_n}{d\,\mu^2}\cos 2\,\phi$$
$$+\ \&c.$$

In order to find $\beta^{(0)}$, we may observe that $\beta^{(0)}\,Q_{2n}\,Q'_{2n}$ is the term independent of ϕ in the coefficient of $\frac{r'^{2n}}{r^{2n+1}}$. Now we have

$$\frac{1}{f}=\frac{1}{\sqrt{\{r^2-2\,r\,r'\,(\mu\,\mu'+\sqrt{(1-\mu^2)}\,\sqrt{(1-\mu'^2)}\cos\phi+r'^2)\}}}$$
$$=\frac{1}{\sqrt{\{r^2-2\,r\,r'\cos\phi+r'^2\}}}+\ \&c.$$

the other terms involving μ, μ'. And

$$\frac{1}{\sqrt{\{r^2-2\,r\,r'\cos\phi+r'^2\}}}=\frac{1}{r}\left(1-\frac{r'}{r}\,c^{\phi\sqrt{-1}}\right)^{-\frac{1}{2}}\left(1-\frac{r'}{r}\,c^{-\phi\sqrt{-1}}\right)^{-\frac{1}{2}}$$

c being the base of the Napierian logarithms,

$$=\frac{1}{r}\left\{1+\frac{1}{2}\,\frac{r'}{r}\,c^{\phi\sqrt{-1}}+\frac{1\,.\,3}{2\,.\,4}\cdot\frac{r'^2}{r^2}\,c^{2\phi\sqrt{-1}}+\ \ldots\ldots\right\}$$
$$\times\left\{1+\frac{1}{2}\,\frac{r'}{r}\,c^{-\phi\sqrt{-1}}+\frac{1\,.\,3}{2\,.\,4}\,\frac{r'^2}{r^2}\,c^{-2\phi\sqrt{-1}}+\ \&c.\right\}$$

and the term which does not involve ϕ, and which does involve $\frac{r'^{2n}}{r^{2n+1}}$ is obviously that which arises from the factors

$$\frac{1}{r}\times\frac{1\,.\,3\ldots 2\,n-1}{2\,.\,4\ldots\ldots 2\,n}\cdot\frac{r'^n}{r^n}\,c^{n\phi\sqrt{-1}}\times\frac{1\,.\,3\ldots(2\,n-1)}{2\,.\,4\ldots\ldots 2\,n}\,\frac{r'^n}{r^n}\,c^{-n\phi\sqrt{-1}}$$

Hence it is clear that we have $\left(\frac{1\,.\,3\ldots\ldots(2\,n-1)}{2\,.\,4\ldots\ldots\ 2\,n}\right)^2=$ the part of $\beta^{(0)}\,Q_{2n}\,Q'_{2n}$, which is independent of μ, μ'. Now since

$$Q_{2n}=\frac{1\,.\,3\,.\,5\ldots(4\,n-1)}{1\,.\,2\,.\,3\ldots\ldots\ 2\,n}\left\{\mu^{2n}-\frac{2\,n\,(2\,n-1)}{2\,(4\,n-1)}\,\mu^{2n-2}+\ \&c.\right\}$$

it is easily seen that the part independent of μ is

$$\pm\frac{1\,.\,3\,.\,5\ldots\ldots(4\,n-1)}{1\,.\,2\,.\,3\ldots\ldots\ 2\,n}\cdot\frac{2\,n\,.\,(2\,n-1)\ldots\ldots 1}{2\,.\,4\,.\,6\ldots\ldots 2\,n\,.\,(4\,n-1)\,(4\,n-3)\ldots\ldots(2\,n+1)}$$
$$=\pm\frac{1\,.\,3\,.\,5\ldots\ldots(2\,n-1)}{2\,.\,4\,.\,6\ldots\ldots\ 2\,n}.$$

And hence in $\beta^{(0)}\,Q_{2n}\,Q'_{2n}$ the part independent of μ, μ' is

$$\beta^{(0)}\left(\frac{1\,.\,3\,.\,5\ldots\ldots(2\,n-1)}{2\,.\,4\,.\,6\ldots\ldots\ 2\,n}\right)^2;\ \text{whence it appears that}\ \beta^{(0)}=1.$$

Hence $$U_n=Q_n\,Q'_n+\beta^{(1)}\,(1-\mu^2)^{\frac{1}{2}}\,(1-\mu'^2)^{\frac{1}{2}}\,\frac{d\,Q_n}{d\,\mu}\,\frac{d\,Q'_n}{d\,\mu}\cos\phi+\ldots$$

(245.) *To reduce the value of* V *into a series of terms of double integrals.*

It will be recollected that y' is the thickness of the attracting stratum on the surface of the sphere. At a point, of which the coordinates are r, μ, ω, let it be y. We will suppose that the stratum is symmetrical with respect to the axis from which θ (the angle whose cosine is μ) is measured; so that taking a ring perpendicular to this axis, the thickness is the same in every part. Hence y is the same for any value of ω, and depends on μ alone, of which it is a function. If we further assume that y is a rational and integral function of μ, we may expand it into a series of terms subject to Laplace's equation. Let therefore

$$y = y_0 + y_1 + y_2 + \ldots + y_n + \ldots.$$

whence

$$n(n+1)\, y_n + \frac{d\,.\,(1-\mu^2)\,\dfrac{d\,y_n}{d\,\mu}}{d\,\mu} = 0,$$

the term vanishing which supposes y_n to involve ω. And if we find y_n by the same process as that of which we found U_n, we shall manifestly have a similar result. Hence

$$y = A_0\,Q_0 + A_1\,Q_1 + A_2\,Q_2 + A_3\,Q_3 + \ldots. + A_m\,Q_m + \ldots.$$

when A_0, A_1, &c. do not involve μ, and Q is the same function of μ as before.

Hence if we suppose that we have $y'\,\mu'$, instead of y, μ, we have

$$y' = y'_0 + y'_1 + y'_2 + \ldots. + y'_n + \ldots.$$

$$y' = A_0\,Q'_0 + A_1\,Q'_1 + A_2\,Q'_2 + \ldots. + A_m\,Q'_m + \ldots.$$

Now $V = \int \frac{y'\,d\,s'}{f}$ where $d\,s'$ is the differential of the surface, at the point of which the coordinates are θ', ω'. And it is clear that this differential is $r'\,d\,\theta'\,.\,r'\sin\theta'\,d\,\omega' = -\,r'^2\,d\,\mu'\,d\,\omega'$.

Hence

$$V = -\iint \frac{y'\,r'^2\,d\,\mu'\,d\,\omega'}{f},$$

the integral being taken from $\mu = 1$ to $\mu = -1$. Or, if we change the sign, $V = \iint \frac{y'\,r'^2\,d\,\mu'\,d\,\omega'}{f}$ from $\mu = -1$ to $\mu = 1$, and from $\omega' = 0$ to $\omega = 2\,\pi$.

If now to put for y' its value, we have

$$V = A_0 \iint \frac{Q'_0\,r'^2\,d\,\mu'\,d\,\omega'}{f} + A_1 \iint \frac{Q'_1\,r'^2\,d\,\mu'\,d\,\omega'}{f} + \ldots. + A_m \iint \frac{Q'_m\,r'^2\,d\,\mu'\,d\,\omega'}{f} + \ldots.$$

And we have the expansion of $\frac{1}{f}$, viz.

$$\frac{1}{f} = \frac{1}{r}\,U_0 + \frac{r'}{r^2}\,U_1 + \ldots. + \frac{r'^n}{r^{n+1}}\,U_n + \ldots.$$

Hence it appears that the value of V will consist of such terms as

$$A_m \iint Q'_m\,U_n\,\frac{r'^{n+2}}{r^{n+1}}\,d\,\mu'\,d\,\omega'$$

(246.) *To execute the integration in* ω'.

If we put for U_n its value in (244), which we may represent thus,

$$U_n = Q_n\,Q'_n + M\cos\phi + M'\cos 2\,\phi +, \&c.$$

M, M' not involving ϕ; we shall find for the general term of V, just mentioned, observing that $\phi = \omega - \omega$,

$$A_m \left\{ \iint Q'_m\,Q'_n\,Q_n\,\frac{r'^{n+2}}{r^{n+1}}\,d\,\mu'\,d\,\omega' + \iint Q'_m\,M\,\frac{r'^{n+2}}{r^{n+1}}\,d\,\mu'\cos(\omega-\omega')\,d\,\omega' +, \&c. \right\}$$

And when we perform the integration in ω', it is clear that the terms after the first will involve $\sin(\omega - \omega')$, $\sin 2\,(\omega - \omega')$, &c. and will therefore vanish when taken from $\omega = 0$ to $\omega = 2\,\pi$. Hence the whole expression will be reduced to terms such as

$$2\,\pi\,A_m \int Q'_m\,Q'_n\,Q_n\,\frac{r'^{n+2}}{r^{n+1}}\,d\,\mu';$$

or supposing r' constant, the terms are

$$2\,\pi\,A_m\,Q_n\,\frac{r'^{n+2}}{r^{n+1}} \int Q'_m\,Q'_n\,d\,\mu'.$$

(247.) *The integrals in μ' vanish, except when $m = n$.*

By equation (D), putting μ' and Q'_n for γ and U_n, we have

$$n(n+1)\,Q'_n + \frac{d\,.\,(1-\mu'^2)\,\frac{d\,Q'_n}{d\,\mu'}}{d\,\mu'} = 0 \text{ ....} \quad \text{(E)}$$

$$\therefore \int Q'_n\,Q'_m\,d\,\mu' = -\frac{1}{n(n+1)} \int \frac{d\,.\,(1-\mu'^2)\,\frac{d\,Q'_n}{d\,\mu'}}{d\,\mu'}\;Q'_m\,d\,\mu'$$

and integrating successively *by parts*,

$$= -\frac{1}{n(n+1)}\,(1-\mu'^2)\,\frac{d\,Q'_n}{d\,\mu'}\,.\,Q'_m + \frac{1}{n(n+1)}\int (1-\mu^2)\,\frac{d\,Q'_n}{d\,\mu'}\,\frac{d\,Q'_m}{d\,\mu'}\,d\,\mu'$$

$$= -\frac{1}{n(n+1)}\,(1-\mu'^2)\,\frac{d\,Q'_n}{d\,\mu'}\;Q'_m + \frac{1}{n(n+1)}\,(1-\mu^2)\,\frac{d\,Q'_m}{d\,\mu'}\,.\,Q'_n$$

$$-\frac{1}{n(n+1)} \int \frac{d\,(1-\mu'^2)\,\frac{d\,Q'_m}{d\,\mu'}}{d\,\mu'}\,.\,Q'_n\,d\,\mu'.$$

And by the same equation (E) the last integral is $- m(m+1) \int Q'_m\,Q'_n\,d\mu'$. Hence, considering that the integrals are taken from $\mu' = -1$ to $\mu' = 1$, and that therefore the parts involving $1 - \mu'^2$ will vanish, we have

$$\int Q'_n\,Q'_m\,d\,\mu' = \frac{m(m+1)}{n(n+1)} \int Q'_m\,Q'_n\,d\,\mu',$$

whence it appears that if m and n are different, $\int Q'_m\,Q'_n\,d\,\mu' = 0$.

Hence it appears that the value of V consists of terms such as

$$2\,\pi\,A_n\,Q_n\,\frac{r'^{\,n+2}}{r^{n+1}} \int Q'_n\,Q'_n\,d\,\mu'.$$

(248.) *To integrate* $\int Q'_n\,Q'_n\,d\,\mu'$.

By equation (E) we have

$$\int Q'_n\,Q'_n\,d\,\mu' = -\frac{1}{n(n+1)} \int \frac{d\,.\,(1-\mu'^2)\,\frac{d\,Q'_n}{d\,\mu'}}{d\,\mu'}\,.\,Q'_n\,;$$

and integrating by parts

$$= -\frac{1}{n(n+1)}\,(1-\mu'^2)\,\frac{d\,Q'_n}{d\,\mu'}\;Q'_n + \frac{1}{n(n+1)} \int (1-\mu'^2)\,\frac{d\,Q'_n}{d\,\mu'}\,.\,\frac{d\,Q'_n}{d\,\mu'}\,d\,\mu'.$$

And since the integral is taken from $\mu' = -1$ to $\mu' = 1$,

$$\int Q'_n\,Q'_n\,d\,\mu' = \frac{1}{n(n+1)} \int (1-\mu'^2)\,\frac{d\,Q'_n}{d\,\mu'}\,\frac{d\,Q'_n}{d\,\mu'}\,d\,\mu'.$$

In the same manner, using Ivory's equation (I), (242), putting Q'_n for U_n, μ' for γ, and making m successively 1, 2, &c. we shall have

$$\int (1-\mu'^2)\,\frac{d\,Q'_n}{d\,\mu'}\,\frac{d\,Q'_n}{d\,\mu'}\,d\,\mu' = \frac{1}{(n-1)(n+2)} \int (1-\mu'^2)^2\,\frac{d^2\,Q'_n}{d\,\mu'^2}\,\frac{d^2\,Q'_n}{d\,\mu'^2}\,d\,\mu'$$

$$\int (1-\mu'^2)^2\,\frac{d^2\,Q'}{d\,\mu'^2}\,\frac{d^2\,Q'}{d\,\mu'^2}\,d\,\mu' = \frac{1}{(n-2)(n+3)} \int (1-\mu'^2)^3\,\frac{d^3\,Q'_n}{d\,\mu'^3}\,\frac{d^3\,Q'_n}{d\,\mu'^3}\,d\,\mu',$$

&c. = &c.

Whence we have

$$\int Q'_n\,Q'_n\,d\,\mu' = \frac{1}{1\,.\,2\,\ldots\ldots\ldots\,2\,n} \int (1-\mu'^2)^n\,.\,\frac{d^n\,Q'_n}{d\,\mu'^n}\,\frac{d^n\,Q'_n}{d\,\mu'^n}\,.\,d\,\mu'.$$

And it is seen by referring to the value of Q_n and Q'_n, in (244.) that

$$\frac{d^n Q'_n}{d\mu'^n} = 1 . 3 . 5 \ldots . (2n - 1).$$

Hence $$\int Q'_n Q'_n \, d\mu' = \frac{(1 . 3 . 5 \ldots . \; (2n - 1))^2}{1 . 2 . 3 \ldots\ldots \; 2n} \int (1 - \mu'^2)^n \, d\mu'.$$

Also it may easily be shown that between the limits $\mu' = -1$ and $\mu' = 1$, we have

$$\int (1 - \mu'^2)^n \, d\mu' = 2 \, . \, \frac{2n . 2(n-1) \ldots\ldots\ldots 2}{(2n + 1)(2n - 1) \ldots . 3}.$$

Hence $$\int Q'_n Q'_n \, d\mu = \frac{2}{2n + 1} \, . \, \frac{2n . 2(n-1) \ldots\ldots\ldots 2}{(2n - 1)(2n - 3) \ldots . 1} \, . \, \frac{(1 . 3 \ldots . 2n - 1)^2}{1 . 2 \ldots\ldots 2n};$$
$$= \frac{2}{2n + 1}$$

(249.) *To find the value of* V.

The general term of V is $$\frac{4\pi}{2n + 1} A_n Q_n \frac{r'^{n+2}}{r^{n+1}}.$$

And it has been seen that $A_n Q_n = y_n$, where y_n is the general term of the expansion of the thickness at the point of which the ordinates are θ, ω. Hence the general term of V is $\frac{4\pi y_n}{2n + 1} \cdot \frac{r'^{n+2}}{r^{n+1}}$. And hence, if for r' we put a, the radius of the sphere, we shall have

$$V = \frac{4\pi a^2}{r} \left\{ y_0 + \frac{a}{3r} y_1 + \frac{a^2}{5r^2} y_2 + \frac{a^3}{7r^3} y_3 + \ldots . + \frac{a^n}{(2n + 1) r^n} y_n + \&c. \right\}$$

(250.) If the point attracted be within the sphere, the process will be the same, except that we must expand V according to powers of $\frac{r}{r'}$. We shall have $\frac{1}{f} = \frac{1}{r'} U_0 + \frac{r}{r'^2} U_1 + \frac{r^2}{r'^3} U_2 + \&c.$ when U_0, U_1, U_2, &c. are the same as before; and we shall find that V consists of terms $A_m \iint Q'_m U_n \frac{r^n}{r'^{n-1}} d\mu' d\omega'$. Also the integrals will vanish, except when $n = m$, and we shall have for V a series of terms $\frac{4\pi y_n}{2n+1} \frac{r^n}{r'^{n-1}}$. And hence, making $r' = a$, we have

$$V = 4\pi a \left\{ y_0 + \frac{r}{3a} y_1 + \frac{r^2}{5a^2} y_2 + \ldots . + \frac{r^n}{(2n + 1) a^n} y_n + \&c. \right\}$$

Hence, whatever be the law of the thickness of the stratum, we can find its attraction upon any point, in any direction, by expanding the expression for the thickness into a series of Laplace's coefficients, and giving to the terms those values which they have at the point where the surface is met by the line r drawn to the attracted point.

(251.) In these values of V the expressions involve μ and $\frac{r}{a}$.

If we put $$\phi(\mu, x) = A_0 Q_0 + \frac{x}{3} A_1 Q_1 + \frac{x^2}{5} A_2 Q_2 + \&c.$$

we shall have the value of V,

for an exterior point $$= \frac{4\pi a^2}{r} \phi\left(\mu, \frac{a}{r}\right);$$

for an interior point $$= 4\pi a \, \phi\left(\mu, \frac{r}{a}\right).$$

(252.) *Knowing* ϕ *when* $\mu = 1$, *to find its general value.*

We have $$\frac{1}{\sqrt{(r^2 - 2\mu r a + a^2)}} = \frac{1}{r} Q_0 + \frac{a}{r^2} Q_1 + \frac{a^2}{r^3} Q_2 + \&c.$$

And when $\mu = 1$, this becomes $$\frac{1}{r - a} = \frac{1}{r} + \frac{a}{r^2} + \frac{a^2}{r^3} + \&c.$$

Hence for this case Q_0, Q_1, Q_2, &c. are each $= 1$.

Therefore making $\mu = 1$, we have $$\phi(1, x) = A_0 + \frac{x}{3} A_1 + \frac{x^2}{5} A_2 + \&c.$$

Hence if when $\mu = 1$, the value of $\phi(\mu, x)$ is $f x$, we must expand $f x$ in a series, according to powers of x; and multiplying the terms of this series by Q_0, Q_1, Q_2, &c. which are known functions of μ, we shall have the value of $\phi(\mu, x)$ for any value of μ.

It appears from this, that if we know the value of V, for any point situate in the axis of the sphere, we can find it for any point in any other situation.

If we make $\mu = -1$, we shall have $\dfrac{1}{r+a} = \dfrac{1}{r} - \dfrac{a}{r^2} + \dfrac{a^2}{r^3} - \&c.$

Hence
$$\phi(-1, x) = A_0 - \frac{x}{3} A_1 + \frac{x^2}{5} A_2 - \&c.$$

And hence, if in $f x$ we put $-x$ instead of x, and multiply the terms by Q_0, Q_1, Q_2, we shall have the value of $\phi(\mu, x)$ corresponding to the point opposite to the point where $\mu = 1$.

(253.) *Knowing $\phi(\mu, x)$ to find the thickness at any point.*

We have
$$\phi(\mu, x) = y_0 + \frac{x}{3} y_1 + \frac{x^2}{5} y_2 + \frac{x^3}{7} y_3 + \&c.$$

$$\therefore \frac{d\phi(\mu, x)}{dx} = \frac{1}{3} y_1 + \frac{2x}{5} y_2 + \frac{3x^2}{7} y_3 + \&c.$$

Hence
$$\phi(\mu, x) + 2x \frac{d\phi(\mu, x)}{dx} = y_0 + x y_1 + x^2 y_2 + x^3 y_3 + \&c.$$

and, making $x = 1$,
$$= y_0 + y_1 + y_2 + y_3 + \&c. = y,$$

whence y the thickness is known.

At the extremities of the diameter from which the angle is measured, we have $\mu = 1$, and $\mu = -1$; which gives the same result as putting $f x$ for $\phi(\mu, x)$. Hence at these points we have

$$y = f x + 2x \frac{df x}{dx};$$

and we must make $x = 1$ for the thickness at the point where $\mu = 1$, and $x = -1$ for the point diametrically opposite.

§ II. *Distribution of a stratum of fluid on two spheres acting upon one another.*

(254.) When a sphere contains equal quantities of positive and negative electricity, the two fluids will be uniformly distributed through its substance, and each particle of one fluid will be accompanied by an equal portion of the other; and hence, as one of them attracts what the other repels, their united effect on any point will be nothing. And hence, if we had two such spheres, their effect on one another will be nothing, and they will remain in this state. But if one of the spheres contain an excess of one of the fluids, as, for instance, of the positive, this excess will distribute itself on the surface, and form a thin stratum there. And this stratum will exert a certain action on the particles of another sphere; and by attracting the negative, and repelling the positive fluid, it may separate them, and cause portions of them to proceed to the surface. By this means the effective parts of the fluids will be a thin stratum at the surface of each sphere, the action of which may be calculated by the preceding formulas; and the law according to which the thickness will vary on each sphere will depend on their mutual action.

In order to calculate the thickness of the stratum of electricity on each sphere, we must know their magnitude and position, and the excess of one kind of electricity above the other on each sphere. By the mutual action of the two spheres, it may happen that besides the original excess of one kind of electricity, some portion of the fluids in the interior of the spheres may be separated, or *decomposed*, and carried to the surface. By this means the quantity of one fluid, the positive for instance, at the surface, may be increased; but in such cases the *excess* of the positive above the negative will remain the same as if no such action had been exerted, because equal quantities of both are always separated. The negative fluid will occupy a portion of the surface, and the thickness y must be reckoned negative for all points when this occurs. In fact, the mechanical action of these points will be obtained by changing the sign of the quantities which express the mechanical action of the portions, supposing them to have been positive.

(255.) *To find the quantity of fluid in a stratum on the surface of a sphere.*

It is easily seen then $\iint y a^2 \, d\mu \, d\omega$ is the content of the stratum, in which the integrals are to be taken from $\omega = 0$ to $\omega = 2\pi$, and from $\mu = -1$ to $\mu = 1$. If both the fluids occur in different parts of the surface, y will be positive in some points and negative in others, and the integral will still represent the excess as before. Let this excess $=$ E.

Now
$$y = A_0 Q_0 + A_1 Q_1 + A_2 Q_2 + \&c.$$

$$\therefore E = \iint y a^2 \, d\mu \, d\omega = a^2 \left\{ A_0 \iint Q_0 \, d\mu \, d\omega + A_1 \iint Q_1 \, d\mu \, d\omega + A_2 \iint Q_2 \, d\mu \, d\omega + \&c. \right\}$$

Now
$$\frac{1}{\sqrt{(r^2 - 2\mu r r' + r'^2)}} = \frac{1}{r} Q_0 + \frac{r'}{r^2} Q_1 + \frac{r'^2}{r^3} Q_2 + \&c. \ldots\text{See (241.) and (244.)}$$

Hence
$$Q_0 = 1, \ Q_1, = \mu, \ \&c.; \text{ and we have}$$

$$E = a^2 \left\{ A_0 \iint Q_0 Q_0 \, d\mu \, d\omega + A_1 \iint Q_0 Q_1 \, d\mu \, d\omega + A_2 \iint Q_0 Q_2 \, d\mu \, d\omega + \&c. \right\}$$

$$= 2\pi a^2 \left\{ A_0 \int Q_0 Q_0 \, d\mu + A_1 \int Q_0 Q_1 \, d\mu + A_2 \iint Q_0 Q_2 \, d\mu + \&c. \right\}$$

And by art. 247. all these terms vanish except the first. Hence $E = 4\pi a^2 A_0$.

Cor. Since $4\pi a^2$ is the surface of the sphere, $A_0 = \frac{E}{4\pi a^2}$ is the thickness of the stratum of fluid, on the supposition that it is uniformly distributed; that is, supposing the fluid on the sphere not to be acted on by any other electrical body.

But $$f x = A_0 + \frac{x}{3} A_1 + \frac{x^2}{5} A_2 + \&c.$$

Hence we have A_0 by making $x = 0$ in $f x$.

(256.) *To find the action of two spheres on any point within one of them.*

Let b be the radius of the second sphere, r_1 μ_1 the coordinates of the attracted point corresponding to r, μ; $\psi(\mu_1, x_1,)$ the function analogous to $\phi(x, \mu)$; and V_1 the sum of each particle of the second sphere, divided by its distance from the attracted point. We shall then have, by art. 251.

for an interior point $$V_1 = 4\pi b \, \psi\left(\mu_1, \frac{r}{b}\right)$$

for an exterior point $$V_1 = \frac{4\pi b^2}{r_1} \psi\left(\mu_1, \frac{b}{r_1}\right)$$

Hence if $W = V + V_1$, the sum of each attracting particle divided by its distance, we shall have for an attracted point within the first sphere

$$W = 4\pi a \, \phi\left(\mu, \frac{r}{a}\right) + \frac{4\pi b^2}{r} \psi\left(\mu_1, \frac{b}{r_1}\right)$$

And, for a point within the second sphere,

$$W = 4\pi \frac{a^2}{r} \phi\left(\mu, \frac{a}{r}\right) + 4\pi b \, \psi\left(\mu_1, \frac{r_1}{b}\right)$$

And, as has been shown, art. 238. by differentiating W we find the attraction on the point in any direction.

(257.) *To find the value of $f x$, art. 252. when the spheres act upon one another.*

In order that the fluids may be in equilibrium, their action on a point within each of the spheres must be nothing; for if it were either attractive or repulsive it would separate the particles of the fluids in the interior of the body, and an additional portion of each would go to the surface. Hence the differentials of W, with respect to r and to μ, and also to r_1, and μ_1, must $= 0$; and therefore W must be independent of r and μ, r_1 and μ_1. Hence it must be equal to a constant quantity, for any point within either of the two spheres. Therefore let h and k be two constant quantities, and let the line of origin be that which joins the centres. Then

$$\left.\begin{aligned} a\,\phi\left(\mu, \frac{r}{a}\right) + \frac{b^2}{r_1} \psi\left(\mu_1, \frac{b}{r_1}\right) &= h \\ \frac{a^2}{r} \phi\left(\mu, \frac{a}{r}\right) + b\,\psi\left(\mu_1, \frac{r_1}{b}\right) &= k \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots (F)$$

r and r_1, μ, and μ_1 being connected by the condition that r and r_1 are the sides of a triangle, of which the third side is the distance of the centres of the spheres, and μ, μ_1 the cosines of the angles adjacent to these.

But it has been seen, art. 252. that it is sufficient to know $f x$ in order to determine $\phi(\mu, x)$; and if $g\,x$ be related in the same manner to $\psi\,x$, we shall have, making $\mu = 1$,

$$\left.\begin{aligned} a f\left(\frac{r}{a}\right) + \frac{b^2}{r_1} g\left(\frac{b}{r_1}\right) &= h \\ \frac{a^2}{r} f\left(\frac{a}{r}\right) + b\,g\left(\frac{r_1}{b}\right) &= k \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (G)$$

where $r + r_1 = c$, the distance between the centres; and r and r_1 may have any values, from $r = a$ to $r = -a$, and from $r_1 = b$ to $r = -b_1$.

In order to eliminate one of the unknown functions f, g, we shall, in the second equation, put r' and $c - r'$ for r and r_1; and let r' be such that

$$\frac{c - r'}{b} = \frac{b}{r_1} = \frac{b}{c - r}$$

therefore $$r' = c - \frac{b^2}{c - r} = \frac{c(c - r) - b^2}{c - r};$$

and the equations (G) become $$a f\left(\frac{r}{a}\right) + \frac{b^2}{c-r}\, g\, \frac{b}{c-r} = h$$

$$\frac{a^2(c-r)}{c(c-r)-b^2} f\left(\frac{a(c-r)}{c(c-r)-b^2}\right) + b\, g\left(\frac{b}{c-r}\right) = k$$

and eliminating g

$$a f\left(\frac{r}{a}\right) - \frac{a^2 b}{c(c-r)-b^2} f\left(\frac{a(c-r)}{c(c-r)-b^2}\right) = h - \frac{k b}{c-r} \text{ .... (H)}$$

whence f is to be determined.

The determination of f in this case has been considered by Mr. Poisson, (*Mém. de l'Institut*, 1811, part ii. p. 183;) but as the investigation is of considerable complexity, and as we have not a series of experimental results to compare with our theoretical ones, we shall leave it at present, in order to consider the simpler case, in which the spheres are in contact.

(258.) *To find the constant quantities h and k.*

If in equations (G) we make $r = 0$, and observe that $f(0) = A_0$, art. 252. we have $a A_0 + \frac{b^2}{c} g\left(\frac{b}{c}\right) = h.$

And if B_0 be the corresponding quantity for the second sphere, making $r_1 = 0$, $g(0) = B_0$; and

$$\frac{a^2}{c} f \frac{a}{c} + b B_0 = k.$$

If E and F be the whole quantities of excess of electricity in the spheres, we shall have

$$E = 4\pi a^2 A_0,\ F = 4\pi b^2 B_0.$$

$$\therefore h = \frac{E}{4\pi a} + \frac{b^2}{c} g\left(\frac{b}{c}\right),\ k = \frac{F}{4\pi b} + \frac{a^2}{c} f\left(\frac{a}{c}\right).$$

§ III. *On the distribution of a fluid on the surfaces of two spheres in contact.*

(259.) *In this case to find the function f.*

When the two spheres are in contact, we shall have $c = a + b$. Hence equations (G) become, observing that $r + r_1 = c$

$$\left.\begin{aligned} a f\left(\frac{r}{a}\right) + \frac{b^2}{a+b-r} g\left(\frac{b}{a+b-r}\right) &= h \\ \frac{a^2}{a+b-r_1} f\left(\frac{a}{a+b-r_1}\right) + b\, g\left(\frac{r_1}{b}\right) &= k \end{aligned}\right\} \text{ .... (a)}$$

And equation (H) will become

$$a f\left(\frac{r}{a}\right) - \frac{a^2 b}{(a+b)(a+b-r)-b^2} f\left(\frac{a(a+b-r)}{(a+b)(a+b-r)-b^2}\right) = h - \frac{k b}{a+b-r} \text{ .... (b)}$$

Let $\frac{r}{a} = 1 - z$, whence $a - r = a z$, and the equation becomes

$$a f(1-z) - \frac{a b}{(b+az)+bz} f\left(\frac{(b+az)}{(b+az)+bz}\right) = h \quad \frac{k b}{b+az}$$

or, multiplying by $\frac{z}{a}$ &c.

$$z f(1-z) - \frac{b z}{b+az+bz} f\left(1 - \frac{b z}{b+az+bz}\right) = \frac{h}{a} \quad \frac{k b z}{a(b+az)}.$$

If we make $\frac{b}{a+b} = m$, we shall have $b = \frac{m a}{1-m}$; and

$$z f(1-z) - \frac{m z}{m+z} . f\left(1 - \frac{m z}{m+z}\right) = \frac{h z}{a} - \frac{k m z}{a(m+(1-m)z)} \text{ .... (c)}$$

If the right-hand side of this equation were $= 0$, it is manifest that it would be satisfied by making $z f(1 \quad z) = C$ a constant, or $f(1-z) = \frac{C}{z}$; for then, putting $\frac{m z}{m+z}$ for z, we should have also

$$\frac{m z}{m+z} f\left(1 - \frac{m z}{m+z}\right) = C.$$

Chap. II.

If we consider the term $\frac{hz}{a}$ on the right-hand side, it will be seen that we may satisfy the equation, by supposing $zf(1-z)$ to be equal to a certain definite integral, depending on a new variable t, which disappears in performing the integration between certain limits. Let $zf(1-z) = C' \int \frac{t^{\frac{m}{z}-1} - 1}{1-t}\, dt$ from $t = 0$ to $t = 1$; then putting $\frac{mz}{m+z}$ for z, $\frac{mz}{m+z} f\left(1 - \frac{mz}{m+z}\right) = C' \int \frac{t^{\frac{m}{z}} - 1}{1-t}\, dt$,

and the first side becomes $C' \int t^{\frac{m}{z}-1}\, dt = \frac{C'z}{m} t^{\frac{m}{z}}$, (when taken from $t = 0$ to $t = 1$) $= \frac{C'z}{m}$;

and satisfies the condition if $\frac{C'}{m} = \frac{h}{a}$, or $C' = \frac{mh}{a}$.

In the same manner, if we consider the term on the right-hand side, $-\frac{kmz}{a(m+(1-mz)}$, it will be seen that we may satisfy it by making

$$zf(1-z) = C'' \int \frac{t^{\frac{m}{z}-m} - 1}{1-t}\, dt, \text{ from } t = 0 \text{ to } t = 1.$$

By this assumption we have, putting $\frac{mz}{m+z}$ for z,

$$\frac{mz}{m+z} f\left(1 - \frac{mz}{m+z}\right) = C'' \int \frac{t^{\frac{m}{z}-m+1} - 1}{1-t}\, dt,$$

and thus the first side of equation (c) becomes

$$C'' \int t^{\frac{m}{z}-m}\, dt = C'' \frac{t^{\frac{m}{z}-m+1}}{\frac{m}{z}-m+1};$$

(taking t from 0 to 1) $\qquad = \frac{C''z}{m+(1-m)z}$;

which coincides with $\qquad -\frac{kmz}{a(m+(1-m)z)}$,

if $\qquad C'' = -\frac{km}{a}$.

Hence the whole equation (c) will be satisfied, if we add together these terms, and make

$$zf(1-z) = C + \frac{mh}{a} \int \frac{t^{\frac{m}{z}-1} - 1}{1-t}\, dt - \frac{mk}{a} \int \frac{t^{\frac{m}{z}-m} - 1}{1-t}\, dt \quad \ldots\ldots\ldots\ldots\ldots\ldots (d)$$

for each part on the left hand will produce a term agreeing with the corresponding one on the right hand as before, and the whole equation will be satisfied.

Cor. *In this case, $h = k$.*

For making $r = a$, $r_1 = b$ in equations (G), (art. 257), we have

$$af(1) + bg(1) = h,$$
$$af(1) + bg(1) = k.$$

Hence the above expression in (d) reduces to

$$zf(1-z) = C + \frac{mh}{a} \int \frac{1 - t^{1-m}}{1-t} t^{\frac{m}{z}-1}\, dt,$$

whence the form of f is known,

$$f(1-z) = \frac{C}{z} + \frac{mh}{az} \int \frac{1 - t^{1-m}}{1-t} t^{\frac{m}{z}-1}\, dt.$$

The quantity $f\left(\frac{r}{a}\right)$ must be finite from all values from $r = -a$ to $r = +a$; therefore $f(1-z)$ must be finite when $r = a$, or $z = 0$. Hence the term $\frac{C}{z}$ must vanish, and

$$f(1-z) = \frac{m\,h}{a\,z}\int \frac{1-t^{1-m}}{1-t}\,t^{\frac{m}{z}-1}\,d\,t,$$

and
$$z f(1-z) = \frac{m\,h}{a}\int \frac{1-t^{1-m}}{1-t}\,t^{\frac{m}{z}-1}\,d\,t, \quad (t=0,\ t=1).$$

(260.) *To find the function g.*
Take the second of equations (a), viz.

$$\frac{a^2}{a+b-r_1}\,f\left(\frac{a}{a+b-r_1}\right) + b\,g\left(\frac{r_1}{b}\right) = k = h.$$

Let
$$b - r_1 = a\,z_1, \text{ or } r_1 = b - a\,z_1;$$

$$\therefore\ \frac{a}{1+z_1}\,f\left(1-\frac{z_1}{1+z_1}\right) + b\,g\left(1-\frac{a\,z_1}{b}\right) = h,$$

and
$$\frac{b\,z_1}{a}\,g\left(1-\frac{a\,z_1}{b}\right) = \frac{h\,z_1}{a} - \frac{z_1}{1+z_1}\,f\left(1-\frac{z_1}{1+z_1}\right).$$

Putting $\frac{z_1}{1+z_1}$ for z, in the result of the last article, the second side becomes

$$\frac{h\,z_1}{a} - \frac{m\,h}{a}\int \frac{1-t^{1-m}}{1-t}\,.\,t^{\frac{m(1+z_1)}{z_1}-1}\,d\,t$$

$$= \frac{m\,h}{a}\int t^{\frac{m}{z_1}-1}\,d\,t - \frac{m\,h}{a}\int \frac{1-t^{1-m}}{1-t}\,t^{\frac{m}{z_1}+m-1}\,d\,t,$$

(as appears by taking the integral from $t = 0$ to $t = 1$)

$$= \frac{m\,h}{a}\int \frac{1-t^{m}}{1-t}\,t^{\frac{m}{z_1}-1}\,d\,t;$$

$$\therefore\ \frac{b\,z_1}{a}\,g\left(1-\frac{a\,z_1}{b}\right) = \frac{m\,h}{a}\int \frac{1-t^{m}}{1-t}\,t^{\frac{m}{z_1}-}\,d\,t \quad (t=0,\ t=1).$$

And if we make
$$\frac{a\,z_1}{b} = z, \text{ whence } z_1 = \frac{b\,z}{a} = \frac{m\,z}{1-m},$$

we find
$$z\,g(1-z) = \frac{(1-m)\,h}{b}\int \frac{1-t^{m}}{1-t}\,t^{\frac{1-m}{z}-1}\,d\,t.$$

(261.) *To find the constant quantity h, knowing the whole quantity of fluid on the two spheres.*
When the spheres are in contact, it is supposed that the fluid can pass freely from one to the other. Hence it is only the sum of the quantities on the two spheres which is given. And it has been shown, art. 258. that if E be the quantity on the sphere with radius a, $E = 4\,\pi\,a^2 f\,x$, making $x = 0$ in $f\,x$: or $E = 4\,\pi\,a^2 f(1-z)$ making $z = 1$. So if F be the quantity on the other sphere, $F = 4\,\pi\,b^2\,g\,(1-z)$, making $z = 1$. Hence $E + F = 4\,\pi\left\{a^2 f(1-z) + b^2\,g\,(1-z)\right\}$ making $z = 1$.

And by the values just found, putting $\frac{m\,a}{(1-m)}$ for b, and 1 for z,

$$E + F = 4\,\pi\,a\,h\int\left\{m\,\frac{t^{m-1}-1}{1-t} + m\,\frac{t^{-m}-1}{1-t}\right\}d\,t$$

$$= 4\,\pi\,m\,a\,h\int\frac{t^{m-1}+t^{-m}-2}{1-t}\,d\,t,$$

whence h is to be determined.

(262.) *To find the thickness of the stratum of fluid at the point of contact.*

By art. 253. we have the thickness at this point by the formula

$$y = f x + 2 x \frac{d f x}{d x};$$

making $x = 1$;

or

$$y = f(1 - z) - 2(1 - z) \frac{d f(1 - z)}{d z},$$

making $z = 0$.

To find the value of this, let $t = \theta^z$, and the expression for $f(1 - z)$ becomes

$$\frac{m h}{a z} \int \frac{1 - \theta^{(1-m)z}}{1 - \theta^z} \theta^{m-z} z \theta^{z-1} d\theta = \frac{m h}{a} \int \frac{1 - \theta^{(1-m)z}}{1 - \theta^z} \theta^{m-1} d\theta;$$

the limits being $\theta = 0, \theta = 1$.

Expanding according to powers of z, we find

$$\frac{1 - \theta^{(1-m)z}}{1 - \theta^z} = \frac{(1 - m) z l\theta + \frac{1}{2}(1 - m)^2 z^2 (l\theta)^2 + \&c.}{z l\theta + \frac{1}{2} z^2 l\theta^2 + \&c.}$$

$$= (1 - m) \left\{ 1 - \frac{m z}{2} l\theta + \&c. \right\}$$

$$\therefore f(1 - z) = \frac{(1 - m) m h}{a} \int \left\{ \theta^{m-1} d\theta - \frac{m z}{2} \theta^{m-1} . l\theta . d\theta + \&c. \right\}$$

And between the limits we have

$$\int \theta^{m-1} d\theta = \frac{\theta^m}{m} = \frac{1}{m}$$

$$\int \theta^{m-1} l\theta . d\theta = \frac{\theta^m l\theta}{m} - \frac{1}{m} \int \theta^{m-1} d\theta$$

$$= \frac{\theta^m l\theta}{m} - \frac{\theta^m}{m^2}$$

$$= -\frac{1}{m^2}$$

$$\therefore f(1 - z) = \frac{m h}{a} (1 - m) \left\{ \frac{1}{m} + \frac{z}{2 m} + \&c. \right\}$$

$$= (1 - m) \frac{h}{a} \left\{ 1 + \frac{z}{2} + \&c. \right\}$$

$$\frac{d f(1 - z)}{d z} = (1 - m) \frac{h}{2 a} + \&c.$$

And when $z = 0, f(1 - z) = (1 - m) \frac{h}{a}$; $\frac{d f(1 - z)}{d z} = (1 - m) \frac{h}{2 a}$.

Hence, at the point of contact, we have for the thickness of the fluid on the sphere whose radius is a,

$$y = 0.$$

And in the same manner the thickness of the electrical stratum on the other sphere will be 0 at the point of contact.

(263.) *The spheres being separated after being in contact, there is always a greater excess of fluid on the greater sphere.*

When the spheres are separated, so as no longer to act on each other, the thickness of the stratum at the surface of each will be uniform: and it will by art. 253. be found by making $x = 0$ in $f x$ for the first sphere, and $x = 0$ in $g x$ for the second. Hence, if E and F be the quantities of these strata, we have

$$\left. \begin{array}{l} E = 4 \pi a^2 f x \\ F = 4 \pi b^2 g x \end{array} \right\} \text{making } x = 0.$$

Hence

$$F - E = 4 \pi (b^2 g x - a^2 f x), \text{ making } x = 0;$$

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$$= 4\,\pi\,\{b^2\,g\,(1 - z) - a^2 f\,(1 - z)\}\text{ making } z = 1.$$

By art. 259. and 260. $$= 4\,\pi\,\left\{(1 - m)\,h\,b\int\frac{t^{-m} - 1}{1 - t}\,d\,t - m\,h\,a\int\frac{t^{m-1} - 1}{1 - t}\,d\,t\right\}$$

$$= 4\pi\,m\,h\,a\int\left\{\frac{t^{-m} - t^{m-1}}{1 - t}\right\}d\,t;\text{ since } (1 - m)\,b = m\,a,\text{ by art. 259.}$$

But it has been proved by Euler, that between $1 = 0$ and $t = 1$ we have

$$\int\frac{t^{p-1} - t^{n-p-1}}{1 - t^n}\,d\,t = \frac{\pi}{n\tan\frac{p\,\pi}{n}}$$ (Lacroix, *Cal. Diff. et Int.* tom. iii. art. 1197.)

And making $n = 1$, and $p = 1 - m$, we shall find

$p - 1 = -m$, and $n - p - 1 = m - 1$; whence we have

$$\int\frac{t^{-m} - t^{m-1}}{1 - t} = \frac{\pi}{\tan(1 - m)\,\pi} = \pi\cot(1 - m)\,\pi.$$

$$\therefore \mathrm{F} - \mathrm{E} = 4\,\pi^2\,m\,h\,a\,.\cot(1 - m)\,\pi.$$

But if $b > a$, $m > \frac{1}{2}$ and $\cot(1 - m)\,\pi$ is positive: also by art. 261. h is positive when E and F are positive; therefore $\mathrm{F} - \mathrm{E}$ is positive, and $\mathrm{F} > \mathrm{E}$.

(264.) *Two spheres, after being in contact, are removed out of the reach of each other's influence; it is required to find the ratio of the thicknesses of the strata at their surfaces.*

The thickness on each will be uniform; and if A and B be the thicknesses, we have

$\mathrm{E} = 4\,\pi\,a^2\,\mathrm{A}$; $\mathrm{F} = 4\,\pi\,b^2\,\mathrm{B}$. Therefore if β be the ratio

$$\beta = \frac{\mathrm{B}}{\mathrm{A}} = \frac{a^2}{b^2}\cdot\frac{\mathrm{F}}{\mathrm{E}} = \frac{a^2}{b^2}\left\{1 + \frac{\mathrm{F} - \mathrm{E}}{\mathrm{E}}\right\}.$$

And putting for $\mathrm{F} - \mathrm{E}$ and E their values, from art. 263.

$$\mathrm{F} - \mathrm{E} = 4\,\pi^2\,m\,h\,a\cot(1 - m)\,\pi$$

$$\mathrm{E} = 4\,\pi\,a^2\,\frac{m\,h}{a}\int\frac{t^{m-1} - 1}{1 - t}\,d\,t$$

we have $$\beta = \frac{a^2}{b^2}\left\{1 + \frac{\pi\cot(1 - m)\,\pi}{\int\frac{t^{m-1} - 1}{1 - t}\,d\,t}\right\}.$$

And when the radii a and b are known, $m = \dfrac{b}{a + b}$ is known, and β may be determined.

(265.) We have now the means of comparing the results of this theory with observation, by determining the value of β for the cases in which Coulomb has made the experiments. He had spheres of which the radii were respectively as $2 : 1$; $4 : 1$; $8 : 1$; and therefore the values of m are

$$\frac{1}{3},\ \frac{1}{5},\ \frac{1}{9},\text{ respectively.}$$

The integrals to be found for these cases are

$$\int\frac{t^{-\frac{2}{3}} - 1}{1 - t}\,d\,t,\ \int\frac{t^{-\frac{4}{5}} - 1}{1 - t}\,d\,t,\ \int\frac{t^{-\frac{8}{9}} - 1}{1 - t}\,d\,t,$$

taken from $t = 0$ to $t = 1$.

If in the first we make $t = \theta^3$, in the second $t = \theta^5$, and the third $t = \theta^9$, they become respectively

$$3\int\frac{1 - \theta^2}{1 - \theta^3}\,d\,\theta,\ 5\int\frac{1 - \theta^4}{1 - \theta^5}\,d\,\theta,\ 9\int\frac{1 - \theta^8}{1 - \theta^9};$$

taken from $\theta = 0$, to $\theta = 1$.

These integrals can be found by the usual methods for rational fractions, and substituting the numerical results thus obtained, in the last article, we have the values of β for the cases above mentioned.

Coulomb gives the name of *electrical density* to that which we have called the thickness of the stratum; and the following is the comparison of the results of his experiments with theory.

Ratio of the Radii $a : b$.	Values of β, the Ratio of the Thicknesses of the Electrical Stratum on the two Spheres.		Difference of Theory and Observation.
	By Theory.	By Observation.	
2 : 1	1.1601	1.08	+ 0.07
4 : 1	1.3168	1.30	+ 0.01
8 : 1	1.4443	1.65	− 0.15

The agreement of the two first observations with theory is remarkable. In the third case the difference may still be attributed to the errors of observation: and it may be noted, that in this case Coulomb did not determine the distribution of the fluid directly, but having touched the large sphere with the small one twenty-four times in succession, he calculated from the result of this, the distribution of electricity at each contact.

(266.) *To find the limit of β when b is infinitely small.*

When $b = 0$, $m = 0$.

We have
$$\int \frac{t^{m-1} - 1}{1 - t}\, d t = \int \left(\frac{t^m - 1}{1 - t} + t^{m\;1}\right) d t$$
$$= \int \frac{t^m - 1}{1 - t}\, d t + \frac{1}{m}$$

But, by the values of E and F, art. 263. we have
$$\beta = \frac{a^2}{b^2} \cdot \frac{\mathrm{F}}{\mathrm{E}} = \frac{a^2}{b^2} \frac{\int \frac{t^{-m} - 1}{1 - t}\, d t}{\int \frac{t^{m-1} - 1}{1 - t}\, d t};$$
$$= \frac{a^2}{b^2} \frac{\int \frac{t^{-m} - 1}{1 - t}\, d t}{\frac{1}{m} + \int \frac{t^m - 1}{1 - t}\, d t}$$
$$= \frac{a^2}{b^2} \frac{\int \left\{\frac{m\, l \frac{1}{t}}{1 - t} + \frac{m^2}{2} \frac{\left(l \frac{1}{t}\right)^2}{1 - t} + \&c.\right\} d t}{\frac{1}{m} - \int \left\{\frac{m\, l \frac{1}{t}}{1 - t} - \frac{m^2}{2} \frac{\left(l \frac{1}{t}\right)^2}{1 - t} + \&c.\right\} d t}$$

Or since $\frac{a^2}{b^2} = \frac{(1 - m)^2}{m^2}$
$$= (1 - m)^2 \cdot \frac{\int \left\{\frac{l \frac{1}{t}}{1 - t} + \frac{m}{2} \frac{\left(l \frac{1}{t}\right)^2}{(1 - t)} + \&c.\right\} d t}{1 - m^2 \int \left\{\frac{l \frac{1}{t}}{1 - t} - \frac{m}{2} \frac{\left(l \frac{1}{t}\right)^2}{1 - t} + \&c.\right\} d t.}$$

And it is clear that when m becomes 0, this becomes
$$= \int \frac{l \frac{1}{t}}{1 - t}\, d t;$$
$$= \int \left\{l \frac{1}{t}\, d t + l \frac{1}{t} \cdot t\, d t + l \frac{1}{t} \cdot t^2\, d t + \&c. \right\};$$

$$= 1 + \frac{1}{2^2} + \frac{1}{3^2} + \frac{1}{4^2} + \&c.;$$

$$= \frac{\pi^2}{6} = 1.6449, \text{ as is known.}$$

Hence when b is infinitely small, $\beta = 1.6449$.

Coulomb conjectured, from his observations, that by increasing the disproportion of the spheres, the ratio of the electrical densities could never be made to surpass that of 2 : 1. This exceeds the true limit by about one-fifth of the whole.

(267.) *To find the thickness at the point opposite to the point of contact.*

In the expression for the thickness, art. 253.

$$y = 2\,x\,\frac{d\,f\,x}{d\,x} + f\,x$$

we must make $x = -1$; or $z = 2$ in $y = -2\,(1-z)\,\dfrac{d\,f\,(1-z)}{d\,z} + f\,(1-z)$.

Now (art. 259.) $z\,f\,(1-z) = \dfrac{m\,h}{a}\displaystyle\int \frac{1-t^{1-m}}{1-t}\,t^{\frac{m}{z}-1}\,d\,t$, from $t = 0$ to $t = 1$.

Differentiating with respect to z,

$$f(1-z) + z\,\frac{d\,f\,(1-z)}{d\,z} = \frac{m\,h}{a}\int \frac{1-t^{1-m}}{1-t}\,.\,t^{\frac{m}{z}-1}\,d\,t\,l\,\frac{1}{t}\,.\,\frac{m}{z^2}$$

$$= \frac{m^2\,h}{a\,z^2}\int \frac{1-t^{1-m}}{1-t}\,t^{\frac{m}{z}-1}\,d\,t\,l\,\frac{1}{t}.$$

$$\frac{d\,f\,(1-z)}{d\,z} = -\frac{f\,(1-z)}{z} + \frac{m^2\,h}{a\,z^3}\int \frac{1-t^{\cdot-m}}{1-t}\,t^{\frac{m}{z}-1}\,.\,d\,t\,l\,\frac{1}{t}.$$

$$y = f\,(1-z) + 2\,\frac{(1-z)}{z}\,f\,(1-z) - \frac{2\,(1-z)\,m^2\,h}{a\,z^3}\int \frac{1-t^{\;-m}}{1-t}\,t^{\frac{m}{z}-1}\,l\,\frac{1}{t}\,.\,d\,t,$$

when $z = 2$; therefore, Y being the thickness at the point in question,

$$\mathrm{Y} = \frac{m^2\,h}{4\,a}\int \frac{1-t^{1-m}}{1-t}\,t^{\frac{m}{2}-1}\,l\,\frac{1}{t}\,.\,d\,t;$$

$$= \frac{m^2\,h}{4\,a}\int \frac{t^{\frac{m}{2}-1} - t^{\frac{m}{2}}}{1-t}\,l\,\frac{1}{t}\,.\,d\,t.$$

If Z be the thickness on the other sphere opposite to the point of contact, we shall have similarly,

$$z\,g\,(1-z) = \frac{(1-m)\,h}{b}\int \frac{1-t^m}{1-t}\,t^{\frac{1-m}{z}-1}\,d\,t:$$

$$g\,(1-z) + z\,\frac{d\,g\,(1-z)}{d\,z} = \frac{(1-m)^2\,h}{b\,z^2}\int \frac{1-t^m}{1-t}\,t^{\frac{1-m}{z}-1}\,l\,\frac{1}{t}\,d\,t.$$

$$\therefore y = \quad 2\,(1-z)\,\frac{d\,g\,(1-z)}{d\,z} + g\,(1-z)$$

$$= g\,(1-z) + \frac{2\,(1-z)}{z}\,g\,(1-z) - \frac{2\,(1-z)\,(1-m)^2\,h}{b\,z^3}\int \frac{1-t^m}{1-t}\,t^{\frac{1-m}{z}-1}\,l\,\frac{1}{t}\,.\,d\,t$$

and, making $z = 2$,

$$y = \frac{(1-m)^2\,h}{4\,b}\int \frac{1-t^m}{1-t}\,t^{-\frac{m+1}{2}}\,d\,t\,l\,\frac{1}{t} = \frac{(1-m)^2\,h}{4\,b}\int \frac{t^{-\frac{m+1}{2}} - t^{\frac{m-1}{2}}}{1-t}\,l\,\frac{1}{t}\,.\,d\,t.$$

(268.) *To find the thickness opposite the point of contact, when the spheres are equal.*

Here $m = \frac{b}{a+b} = \frac{1}{2}$, and by last article

$$Y = \frac{h}{16\,a}\int \frac{t^{-\frac{3}{4}} - t^{-\frac{1}{4}}}{1-t}\, l\,\frac{1}{t}\, d\,t.$$ And also

$$Z = \frac{h}{16\,a}\int \frac{t^{-\frac{3}{4}} - t^{-\frac{1}{4}}}{1-t}\, l\,\frac{1}{t}\, d\,t.$$

Let $t = \theta^4 \therefore d\,t = 4\,\theta^3\,d\,\theta.$

$$Y = \frac{h}{a}\int \frac{1-\theta^2}{1-\theta^4}\, l\,\frac{1}{\theta}\, d\,\theta = \frac{h}{a}\int \frac{l\,\frac{1}{\theta}}{1+\theta^2}\, d\,\theta,$$

the integral taken from $\theta = 0$ to $\theta = 1$.

By expanding, we have

$$Y = \frac{h}{a}\int\left\{ l\,\frac{1}{\theta}\, d\theta - \theta^2\, l\,\frac{1}{\theta}\, d\,\theta + \theta^4\, l\,\frac{1}{\theta}\, d\,\theta \text{ \&c.}\right\}$$

And, between the limits, $\int \theta^n\, l\,\frac{1}{\theta}\, d\,\theta = \frac{1}{(n+1)^2}$

$$\therefore Y = \frac{h}{a}\left\{\frac{1}{1^2} - \frac{1}{3^2} + \frac{1}{5^2} - \text{\&c.}\right\}$$

And taking a sufficient number of terms for the approximation, we find

$$Y = .916\,\frac{h}{a}.$$

(269.) *To compare this with the mean thickness.*

If A be the mean thickness, which will be the same on both spheres,

we have $A = \frac{E}{4\,\pi\,a^2}$. And since $m = \frac{1}{2}$, by art. (264.)

$$A = \frac{h}{2\,a}\int \frac{t^{-\frac{1}{2}} - 1}{1-t}\, d\,t = \frac{h}{a}\int \frac{d\,\sqrt{t}}{1+\sqrt{t}} = \frac{h}{a}\, l\,2 = .693\,\frac{h}{a}$$

between the limits.

$$\therefore \frac{Y}{A} = \frac{.916}{.693} = 1.322.$$

Coulomb found, by experiment, this ratio equal to 1.27, which differs by less than one twenty-fifth from the value given by theory.

(270.) *To compare the greatest thickness on the less sphere with the mean thickness on the greater sphere.*

Let $\frac{Z}{A} = \gamma$, the ratio sought

By arts. (267.) and (264.)

$$Z = \frac{(1-m)^2\,h}{4\,b}\int \frac{t^{-\frac{m+1}{2}} - t^{\frac{m-1}{2}}}{1-t}\, l\,\frac{1}{t}\,.\,d\,t$$

$$A = \frac{m\,h}{a}\int \frac{t^{m-1} - 1}{1-t}\, d\,t$$

$$\therefore \gamma = \frac{(1-m)^2\,a}{4\,m\,b}\;\frac{\int \frac{t^{-\frac{m+1}{2}} - t^{\frac{m-1}{2}}}{1-t}\, l\,\frac{1}{t}\,.\,d\,t}{\int \frac{t^{m-1} - 1}{1-t}\,.\,d\,t}$$

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and when the radii a and b are known, we know $m = \frac{b}{a+b}$. The coefficient $\frac{(1-m)^2 a}{4\,m\,b}$ becomes $\frac{a^3}{4\,(a+b)^2\,b}$.

(271.) Coulomb's experiments were made with spheres, of which the radii were as 1 : 1, as 2 : 1, as 4 : 1, and as 8 : 1. We shall have to calculate the value of γ for these cases, and to compare it with experiment.

When $b = a$, $m = \frac{1}{2}$, and the value of γ is the same as that of $\frac{\gamma}{A}$ in art. (269.)

When $b = \frac{1}{2}\,a$, $m = \frac{1}{3}$; and the integral in the numerator of γ is $\int \frac{t^{-\frac{2}{3}} - t^{-\frac{1}{3}}}{1-t}\,\mathrm{l}\frac{1}{t}\,d\,t$; and making $t = \theta^3$, this becomes $-\,9\int \frac{1-\theta}{1-\theta^3}\,\mathrm{l}\frac{1}{\theta}\,.\,d\,\theta$. And by expanding, this may be integrated from $\theta = 0$ to $\theta = 1$.

The integral in the denominator is $\int \frac{t^{-\frac{2}{3}} - 1}{1-t}\,d\,t$, which may be made rational, by putting $t = \theta^3$.

When $b = \frac{1}{4}\,a$, $m = \frac{1}{5}$. The integral in the numerator of γ is

$$\int \frac{t^{-\frac{3}{5}} - t^{-\frac{2}{5}}}{1-t}\,\mathrm{l}\frac{1}{t}\,d\,t. \text{ And making } t = \theta^5, \text{ this becomes}$$

$$-\,25\int \frac{\theta - \theta^2}{1-\theta^5}\,\mathrm{l}\frac{1}{\theta}\,.\,d\,\theta;$$ which may be integrated as before; as may the denominator.

When $b = \frac{1}{8}\,a$, $m = \frac{1}{9}$. The integral in the numerator is

$$\int \frac{t^{-\frac{5}{9}} - t^{-\frac{4}{9}}}{1-t}\,\mathrm{l}\frac{1}{t}\,.\,d\,t. \text{ And making } t = \theta^9, \text{ this becomes}$$

$-\,81\int \frac{\theta^3 - \theta^4}{1-\theta^9}\,\mathrm{l}\frac{1}{\theta}\,.\,d\,\theta$; which may be integrated as before. The denominator may also be made rational as before.

Performing these calculations, and comparing them with Coulomb's experiments, we have the following results.

Ratio of the Radii $a : b$.	Values of γ.		Difference of Theory and Observation compared with the whole.
	By Theory.	By Observation.	
1 : 1	1.322	1.27	+ 0.04
2 : 1	1.834	1.55	+ 0.15
4 : 1	2.477	2.35	+ 0.05
8 : 1	3.087	3.18	− 0.03

The last column contains the difference of the value given by theory and that given by observation, divided by the former value.

We now proceed to find the thickness at any point not in the line joining the centres, and for that purpose we must, by (252.), deduce $\phi\,(\mu, x)$ from $f\,x$.

(272.) *To find* $f'(x)$.

$$f(1-z) = \frac{m\,h}{a\,z}\int \frac{1 - t^{1-m}}{1-t}\,t^{\frac{m}{z}-1}\,d\,t, \text{ by (259.)}$$

$$= \frac{m\,h}{a\,z}\int \left(t^{\frac{m}{z}-1} - t^{\frac{m}{z}-m}\right)(1 + t + t^2 + t^3 + \ldots.)\,d\,t$$

Now $$\int t^{\frac{m}{z}-1+n}\,d\,t = \frac{y}{m+n\,y} \text{ taken } t = 0, \text{ to } t = 1$$

$$\int t^{\frac{m}{z} - m + n} \, dt = \frac{z}{m + (n - m + 1) z} :$$

and we have these terms occurring, with all values of n from 0 to ∞.

$$\therefore f(1 - z) = \frac{m h}{a} \left\{ \begin{array}{l} \frac{1}{m} + \frac{1}{m + z} + \frac{1}{m + 2z} \ldots\ldots + \frac{1}{m + nz} + \ldots. \\ - \frac{1}{m + (1 - m) z} - \frac{1}{m + (2 - m) z} \ldots\ldots - \frac{1}{m + (n - m + 1) z} - \ldots. \end{array} \right\}$$

And if we put $1 - x$ for z, we shall have $f x$.

(273.) In order to find $\phi(\mu, x)$, we must expand this expression in powers of x, and multiply the successive terms by Q_0, Q_1, Q_2, &c. which are such that

$$\frac{1}{\sqrt{(1 - 2 \mu x + x^2)}} = Q_0 + Q_1 x + Q_2 x^2 + \ldots. Q_n x^n + \ldots.$$

Hence the term $\frac{1}{m + n y}$ will become

$$\frac{1}{m + n - n x} = \frac{1}{m + n} \left\{ 1 + \frac{n x}{m + n} + \frac{n^2 x^2}{(m + n)^2} + \frac{n^3 x^3}{(m + n)^3} + \text{\&c.} \right\};$$

and will give, in $\phi(\mu, x)$, the terms

$$\frac{1}{m + n} \left\{ Q_0 + \frac{Q_1 n x}{m + n} + \frac{Q_2 n^2 x^2}{(m + n)^2} + \frac{Q_3 n^3 x^3}{(m + n)^3} + \text{\&c.} \right\};$$

which will clearly be equal to

$$\frac{1}{m + n} \left\{ 1 - \frac{2 \mu n x}{m + n} + \frac{n^2 x^2}{(m + n)^2} \right\}^{-\frac{1}{2}} \text{ or } \left\{ (m + n)^2 - 2 \mu (m + n) n x + n^2 x^2 \right\}^{-\frac{1}{2}}$$

Let this be called R_n.

In the same manner the term $- \frac{1}{m + (n - m + 1)(1 - x)}$ will produce in $\phi(\mu, x)$ the expression

$$- \frac{1}{n + 1} \left\{ 1 - \frac{2 \mu (n - m + 1) x}{n + 1} + \frac{(n - m + 1)^2 x^2}{(n + 1)^2} \right\}^{-\frac{1}{2}}$$

or

$$- \left\{ (n + 1)^2 - 2 \mu (n + 1)(n - m + 1) x + (n - m + 1)^2 x^2 \right\}^{-\frac{1}{2}}$$

Let this be called $- S_n$.

We shall then have $\phi(\mu, x) = \frac{m h}{a} \left\{ R_0 - S_0 + R_1 - S_1 + \ldots. + R_n - S_n \ldots. \right\}$

(274.) *To find the thickness of the stratum of fluid at any point of the surface of the spheres.*

We have the thickness on the first sphere by the formula in (253.)

$$y = 2 x \frac{d \phi(\mu, x)}{d x} + \phi(\mu, x),$$

using the value of $\phi(\mu, x)$ in last article, and making $x = 1$ after the differentiation.

On the other sphere we must use $g x$ and $\psi(\mu, x)$ instead of $f x$, and $\phi(\mu, x)$. But it is clear, from (257.), that we shall find $g x$ from $f x$ by putting $1 - m$ for m, and b for a. Hence, by this process, we shall find $\psi(\mu, x)$ from $\phi(\mu, x)$.

(275.) *When the spheres are equal, to find the distribution of the fluid.*

Here $m = \frac{b}{a + b} = \frac{1}{2}$.

$$R_n = 2 \left\{ (2n + 1)^2 - 2 \mu (2n + 1) 2n . x + (2n)^2 x^2 \right\}^{-\frac{1}{2}}$$

$$S_n = 2 \left\{ (2n + 2)^2 - 2 \mu (2n + 2)(2n + 1) x + (2n + 1)^2 x^2 \right\}^{-\frac{1}{2}}$$

Hence if we put $\left\{ (n + 1)^2 - 2 \mu (n + 1) n . x + n^2 x^2 \right\}^{-\frac{1}{2}} = T_n$

we shall have $R_n = 2 T_{2n}$, $S_n = 2 T_{2n+1}$.

$$\therefore \phi(\mu, x) = \frac{h}{a} \{\mathrm{T}_0 - \mathrm{T}_1 + \mathrm{T}_2 - \mathrm{T}_3 + \&c.\}$$

And

$$\frac{d\,\mathrm{T}_n}{d\,x} = \frac{\mu(n+1)\,n - n^2\,x}{\{(n+1)^2 - 2\,\mu\,(n+1)\,n\,.\,x + n^2 x^2\}^{\frac{3}{2}}}$$

And hence, when we make $x = 1$, we have the value of

$$2\,x\frac{d\,\mathrm{T}_n}{d\,x} + \mathrm{T}_n = \frac{2\,n+1}{(n+1)^2 - 2\,\mu\,(n+1)\,n + n^2\}^{\frac{3}{2}}}$$

And if we call this A_n, we shall have the thickness of the stratum

$$y = \frac{h}{a}\{\mathrm{A}_0 - \mathrm{A}_1 + \mathrm{A}_2 - \mathrm{A}_3 + \&c.\}$$

In this formula μ is the cosine of the angular distance of any point from the point of contact, and the series will be sufficiently convergent for all cases, except when μ is nearly equal to 1.

Thus for the point opposite to the point of contact, $\mu = -1$,

$$\mathrm{A}_n = \frac{1}{(2\,n+1)^2}, \text{ and hence}$$

$$y = \frac{h}{a}\left\{1 - \frac{1}{3^2} + \frac{1}{5^2} - \frac{1}{7^2} + \&c.\right\}$$

which agrees with what was found in (268.) by a different method.

(276.) We shall compare the results in this case with those which Coulomb obtained from experiment. Placing two equal spheres in contact, he measured the electrical density at distances, from the point of contact, of 30°, 60°, 90°, and 180°. Now in this case we shall have

$$\text{at } 30^\circ,\ \mu = \frac{\sqrt{3}}{2},\ y = 0.137\,\frac{h}{a};$$

$$\text{at } 60^\circ,\ \mu = \frac{1}{2},\ y = 0.599\,\frac{h}{a};$$

$$\text{at } 90^\circ,\ \mu = 0,\ y = 0.803\,\frac{h}{a};$$

$$\text{at } 180^\circ,\ \mu = -1,\ y = 0.916\,\frac{h}{a}.$$

We can only compare the relative values of these quantities with experiment. Hence let the value of y, corresponding to 90°, be divided by each of the others; and let

$$\frac{\text{thickness at } 90^\circ}{\text{thickness at } 180^\circ} = a,\quad \frac{\text{thickness at } 90^\circ}{\text{thickness at } 60^\circ} = a',\quad \frac{\text{thickness at } 90^\circ}{\text{thickness at } 30^\circ} = a''.$$

We shall then have the following comparison.

	Ratios of Electricity at different Points of equal Spheres in contact.		Difference of Theory and Observation compared with the whole.
	By Theory.	By Observation.	
a	1.877	0.95	− 0.08
a'	1.342	1.25	+ 0.07
a''	5.857	4.80	+ 0.18

The last column contains the excess of the value given by theory above that given by experiment, divided by the former value.

y of ity. (277.) *When the radius of one sphere is double that of the other, to find the distribution of the fluid, on the surface of the smaller sphere.*

Let $b = 2a$, therefore $m = \frac{2}{3}$.

$$\text{Hence } R_n = 3\left\{(3n+2)^2 - 2\mu(3n+2)\,3n\,.\,x + (3n)^2x^2\right\}^{-\frac{1}{2}}$$

$$S_n = 3\left\{(3n+3)^2 - 2\mu(3n+3)(3n+1)\,x + (3n+1)^2x^2\right\}^{-\frac{1}{2}}.$$

Make $\left\{(n+2)^2 - 2\mu(n+2)\,n\,.\,x + n^2x^2\right\}^{-\frac{1}{2}} = U_n$, and we shall have

$$R_n = 3\,U_{3n},\ S_n = 3\,U_{3n+1}.$$

$$\phi(\mu, x) = \frac{2h}{a}\left\{U_0 - U_1 + U_3 - U_4 + \&c.\right\}$$

$$\frac{dU_n}{dn} = \frac{\mu(n+2)\,n - n^2x}{\left\{(n+2)^2 - 2\mu(n+2)\,n\,.\,x + n^2x^2\right\}^{\frac{3}{2}}}$$

$$2x\frac{dU_n}{dn} + U_n = \frac{4(n+1)}{\left\{(n+2)^2 - 2\mu(n+x)\,n\,.\,x + n^2x^2\right\}^{\frac{3}{2}}}.$$

And if B_n be the value of this when $x = 1$,

$$B_n = \frac{4(n+1)}{\left\{(n+2)^2 - 2\mu(n+2)\,n + n^2\right\}^{\frac{3}{2}}},$$

and we shall have for the thickness

$$y = \frac{2h}{a}\left\{B_0 - B_1 + B_3 - B_4 + \&c.\right\}$$

If we give to μ the values corresponding to the angles,

60°, 90°, 180°,

viz. $\mu = \frac{1}{2}$, $\mu = 0$, $\mu = -1$;

we shall find for y the values

$$.321\,\frac{h}{a},\qquad .577\,\frac{h}{a}\qquad .781\,\frac{h}{a},$$

and, as before, we shall make

$$\frac{\text{thickness at } 90°}{\text{thickness at } 180°} = \beta,\quad \frac{\text{thickness at } 90°}{\text{thickness at } 60°} = \beta'.$$

(278.) *In the same case to find the distribution of fluid on the larger sphere.*

We have here to find $\psi(\mu, x)$, for which purpose we must put $1 - m$ for m, and b for a in $\phi(\mu, x)$. Hence in the general expressions for R_n and S_n we must put $\frac{1}{3}$ for m, and we have thus

$$R_n = 3\left\{(3n+1)^2 - 2\mu(3n+1)\,3n\,.\,x + (3n)^2x^2\right\}^{-\frac{1}{2}}$$

$$S_n = 3\left\{(3n+3)^2 - 2\mu(3n+3)(3n+2)\,x + (3n+2)^2x^2\right\}^{-\frac{1}{2}}$$

And, as before, putting $\left\{(n+1)^2 - 2\mu(n+1)\,n\,x + n^2x^2\right\}^{-\frac{1}{2}} = T_n$, we shall have

$R_n = 3\,T_{3n}$, and $S_n = 3\,T_{3n+2}$. Hence

$$\psi(\mu, x) = \frac{h}{b}\left\{T_0 - T_2 + T_3 - T_4 + \&c.\right\}$$

And A_n being the same as in art. (275.), we have for the thickness y,

$$y = \frac{h}{b}\left\{A_0 - A_2 + A_3 - A_5 + \&c.\right\}$$

At 90° from the point of contact $y = .928\,\frac{h}{b} = .464\,\frac{h}{a}$.

At 90° from the point of contact on the other sphere $y = .577\frac{h}{a}$. Hence, at the rings which are 90° from the point of contact, the thickness of the fluid is greater on the smaller sphere.

Let $$\frac{\text{thickness on smaller sphere}}{\text{thickness on larger sphere}} = \beta''.$$

Theory of Electricity.

(279.) We shall compare the results in the two last articles with experiment. The last column is calculated as before.

	Ratios of Electricity at different Points of two Spheres, one Radius being double the other.		Difference of Theory and Observation compared with the whole.
	By Theory.	By Observation.	
β	.739	.75	− 0.01
β'	1.797	1.70	+ 0.05
β''	1.238	1.25	− 0.01

(280.) *When one of the radii is four times the other, to find the distribution of fluid on the smaller sphere.*

As before, if we make $\{(n+4)^2 - 2\mu(n+4)n.x + n^2x^2\}^{-\frac{1}{2}} = V_n,$

we shall have $\phi(\mu, x) = \dfrac{4h}{a}\{V_0 - V_1 + V_5 - V_6 + \&c.\}.$

And if we make $\dfrac{8(n+2)}{\{(n+4)^2 - 2\mu(n+4)n + n^2\}^{\frac{3}{2}}} = C_n,$

we shall have for the thickness y, $y = \dfrac{4h}{a}\{C_0 - C_1 + C_5 - C_6 + \&c.\}.$

And at distances from the point of contact

90°	180°
$\mu = 0$	$\mu = -1$
$y = .349\dfrac{h}{a}$	$y = .584\dfrac{h}{a}$

Let $\dfrac{\text{thickness at } 180^\circ}{\text{thickness at } 90^\circ} = \gamma.$

(281.) The last result being compared with experiment, we have

By Theory.	By Observation.	Difference compared with the whole.
$\gamma = 1.673$	1.43	+ 0.15

(282.) If we take the sums of the differences contained in the last columns of the tables in arts. (265.), (271.), (276.), (279.), (281.), and divide this sum by 14, the whole number of observations, we shall have the mean difference of the results of theory and of experiment. This difference is between .03 and .04, so that it is nearly $\frac{1}{30}$. If we add all the differences together, neglecting the contrary signs, and divide by 14, we shall have a quotient less than $\frac{1}{17}$; and hence it appears that in whatever manner we estimate the mean difference, it is always sufficiently small to be attributed to the errors of observation.

§ IV. *On the distribution of the fluid on the surfaces of two spheres at a considerable distance from each other.*

(283.) *In this case to find $f\,x$ and $g\,x$.*

The distances of the spheres is here supposed to be large compared with one of them, as b. Take the equations (G) of art. (257.)

$$\left.\begin{aligned} a f\left(\frac{r}{a}\right) + \frac{b^2}{r_1} g\left(\frac{b}{r_1}\right) &= h \\ \frac{a^2}{r} f\left(\frac{a}{r}\right) + b g\left(\frac{r_1}{b}\right) &= k \end{aligned}\right\} \ldots\ldots\ldots\ (2)$$

Let $r = a x$, $r_1 = b x = 1 - a x$, 1 being the distance of the centres,

$$\left.\begin{aligned} \therefore\ af(x) + \frac{b^2}{1 - ax} g\left(\frac{b}{1 - ax}\right) &= h \\ bg(x) + \frac{a^2}{1 - bx} f\left(\frac{a}{1 - bx}\right) &= k \end{aligned}\right\} \ldots\ldots\ldots (a)$$

Expanding the terms in the second equation, we have

$$\frac{a^2}{1-bx} = a^2(1 + bx + b^2x^2 + b^3x^3 + \&c.)$$

$$f\left(\frac{a}{1-bx}\right) = f(a) + af'(a)\ bx + \{a^2f''(a) + 2af'(a)\}\frac{b^2x^2}{1.2} + \&c.$$

f', f'', &c. being the derived coefficients from $f(x)$ making $x = a$. Hence the second of equations $(a)'$ gives, omitting cubes, &c. of b,

$$bg(x) = k - a^2f(a) - \{a^2f(a) + a^3f'(a)\}\,bx - \{a^2f(a) + 2a^3f'(a) + \frac{1}{2}a^4f''(a)\}\,b^2x^2 \ldots. \ (\beta)$$

Put $\dfrac{b}{1-ax}$ for x, multiply by $\dfrac{b}{1-ax}$, omitting cubes, &c. of b, and we find

$$\frac{b^2}{1-ax}\,g\left(\frac{b}{1-ax}\right) = \frac{(k - a^2f(a))\,b}{1-ax}.$$

Hence we have from the first of equations (a)

$$af(x) = h - \frac{(k - a^2f(a))\,b}{1-ax} \ldots\ldots\ldots\ldots\ldots (\gamma)$$

Hence differentiating with respect to x, and then making $x = a$,

$$af(a) = h - \frac{(k - a^2f(a))\,b}{1-a^2};$$

$$af'(a) = -\frac{(k - a^2f(a))\,ab}{(1-a^2)^2};$$

$$af''(a) = -\frac{(k - a^2f(a))\,2a^2b}{(1-a^2)\,3};$$

From the first of these three equations we have

$$af(a) = \frac{h - \dfrac{kb}{1-a^2}}{1 - \dfrac{ab}{1-a^2}} = h \cdot (k - ha)\,\frac{b}{1-a^2-ab}.$$

Hence

$$k - a^2f(a) = (k - ha)\,\frac{1-a^2}{1-a^2-ab};$$

and hence, by the preceding values,

$$af'(a) = -\frac{k-ha}{1-a^2}\cdot\frac{ab}{1-a^2-ab}$$

$$af''(a) = -\frac{(k-ha)}{(1-a^2)^2}\,\frac{2a^2b}{1-a^2-ab}.$$

Substituting these values in (γ), and (β), we have

$$af(x) = h - \frac{(k-ha)(1-a^2)\,b}{(1-ax)(1-a^2-ab)} \ldots\ldots\ldots\ldots\ldots (\delta)$$

$$bg(x) = \frac{(k-ha)(1-a^2)}{1-a^2-ab} - \left\{ah - \frac{(k-ha)\,ab}{(1-a^2)(1-a^2-ab)}\right\}bx - ahb^2x^2,$$

the other terms involving b^3, &c.;

or

$$bg(x) = \frac{k-ha}{1-a^2-ab}\left\{1 - a^2 - \frac{ab^2x}{1-a^2}\right\}$$
$$- ah\,bx - ah\,b^2x^2 \ldots\ldots\ldots\ldots (\epsilon)$$

We may in these formulæ expand $\dfrac{1}{1-a^2-ab} = \dfrac{1}{1-a^2} + \dfrac{ab}{(1-a^2)^2}$ &c. and omit the terms involving b^3, &c.

This formula requires b to be small, not only with respect to the distance of the centres, represented by 1, but also with respect to $1 - a$, the distance of the centre of the smaller sphere to the surface of the larger. Hence the formula cannot be applied to the case of contact.

Theory of Electricity.

(284.) *Knowing the quantity of fluid on each sphere, to find h and k.*

Let E be the quantity on the one whose radius is a, F on the one whose radius is b. We shall have, by art. (263.)

$$E = 4\,\pi\,a^2 f(x);\ F = 4\,\pi\,b^2\,g(x), \text{ making } x = 0.$$

Or if A, B, be the thicknesses, supposing them uniform, $A = f(0)$, $B = g(0)$;

$\therefore$ by last article, equations (δ), $$a\,A = h - \frac{(k - h\,a)\,(1 - a^2)\,b}{1 - a^2 - a\,b}$$

$$b\,B = \frac{(k - h\,a)\,(1 - a^2)}{1 - a^2 - a\,b}$$

Hence $$a\,A + b^2\,B = h.$$

And from the second equation $k - h\,a = \dfrac{1 - a^2 - a\,b}{1 - a^2}\,b\,B$;

$$\therefore k = h\,a + \left(1 - \frac{a\,b}{1 - a^2}\right) b\,B, \text{ and putting the above value for } h,$$

$$k = a^2\,A + a\,b^2\,B + \left(1 - \frac{a\,b}{1 - a^2}\right) b\,B$$

$$= a^2\,A + \left(1 - \frac{a^3\,b}{1 - a^2}\right) b\,B.$$

By introducing these values in (δ) and (ϵ) of last article, we find

$$a\,f(x) = A\,a + B\,b^2 - \frac{B\,b^2}{1 - a\,x}$$

$$b\,g(x) = B\,b\left\{1 - \frac{a\,b^2\,x}{(1 - a^2)^2}\right\} - \{A\,a + B\,b^2\}\,\{a\,b\,x + a\,b^2\,x^2\};$$

or, omitting b^3, $b\,g(x) = B\,b - A\,a^2\,b\,x\,(1 + b\,x)$

These values may be put in this form.

$$a\,f(x) = A\,a - \frac{B\,a\,b^2\,x}{1 - a\,x};$$

$$b\,g(x) = B\,b - \frac{A\,a^2\,b\,x}{1 - b\,x}.$$

(285.) *To find the thickness of the stratum of fluid on the sphere with radius a.*

From the method given in art. (273.) for obtaining $\phi(\mu, x)$, it is manifest, from the values in last article, that

$$a\,\phi(\mu, x) = A\,a + B\,b^2 - \frac{B\,b^2}{\sqrt{\{1 - 2\,\mu\,a\,x + a^2\,x^2\}}};$$

and putting this value of $\phi(\mu, x)$ in the formula, $y = 2\,x\,\dfrac{d\,\phi(\mu, x)}{d\,x} + \phi(\mu, x)$, and making $x = 1$, we have

$$y = A + \frac{B\,b^2}{a} - \frac{B\,b^2\,(1 - a^2)}{a\,\sqrt{\{1 - 2\,\mu\,a + a^2\}}}$$

(286.) *To find the thickness of the stratum of fluid on the sphere with radius b.*

By art. (252.)

Since $$b\,g(x) = B\,b - A\,a^2\,b\,x - A\,a^2\,b^2\,x^2,$$

if Q_0, Q_1, Q_2 be the coefficients in the three first terms of the expansion of $\{1 - 2\,\mu\,x + x^2\}^{-\frac{1}{2}}$, we shall have

$$\psi(\mu, x) = B\,Q_0 - A\,Q_1\,a^2\,x - A\,Q_2\,a^2\,b\,x^2.$$

But we find $$Q_0 = 1,\ Q_1 = \mu,\ Q_2 = -\frac{1 - 3\,\mu^2}{2};$$

$$\therefore \psi(\mu, x) = B - A\,a^2\,\mu\,x + \frac{1 - 3\,\mu^2}{2}\,A\,a^2\,b\,x^2.$$

And z being the thickness on the other sphere,

$$z = 2x\frac{d\,\psi(\mu, x)}{d\,x} + \psi\,x, \text{ making } x = 1.$$

$$\therefore\ z = \mathrm{B} - 3\,\mathrm{A}\,a^2\mu + \frac{5}{2}\,(1 - 3\,\mu^2)\,\mathrm{A}\,a^2\,b;$$

and knowing A, B, this will give us the distribution of the fluid.

A, B are the excesses of the *positive* fluid on the respective spheres, and will both be positive if both the spheres are positively electrified. If one or both have an excess of negative or resinous electricity, the corresponding quantities A, B must be negative.

(287.) *Let the small sphere be not electrified; to find the distribution of the fluid upon it.*

Here $\mathrm{B} = 0,\ \therefore\ z = -3\,\mathrm{A}\,a^2\left\{\mu + \frac{5\,b}{6}\,(3\,\mu^2 - 1)\right\}$.

At the point of the sphere which is in the line joining the centres

$$\mu = 1,\ z = -3\,\mathrm{A}\,a^2\left\{1 + \frac{5\,b}{3}\right\}.$$

At the opposite point $\qquad \mu = -1,\ z = 3\,\mathrm{A}\,a^2\left\{1 - \frac{5\,b}{3}\right\}.$

Hence at the first point the fluid is accumulated, which is of a nature opposite to that whose thickness is A; at the second point the fluid is of the same kind as that with thickness A; and the intensities at those points are as $1 + \frac{5\,b}{3} : 1 - \frac{5\,b}{3}$, and therefore nearly equal.

(288.) *In this case to find the line which separates the two fluids on the surface of the smaller sphere.*

Make $z = 0;\ \therefore\ \mu + \frac{5\,b}{6}\,(3\,\mu^2 - 1) = 0;$

$$\therefore\ \mu = \frac{\sqrt{\left(1 + \frac{25\,b^2}{3}\right)} - 1}{5\,b}$$

And neglecting b^3, &c. $\mu = \frac{5\,b}{6}$. Hence the line which separates the fluids is a circle, distant by less than 90° from the vertex of the sphere. Hence the negative fluid (that which is of a different kind from the fluid on the sphere with radius a) occupies less than half the surface. As the distance of the spheres becomes greater with respect to the radius b, the circle which separates the fluids approaches perpetually to the circle bisecting the sphere.

(289.) *When the excess of fluid on the smaller sphere is known, to find its distribution.*

It appears, by art. (286.), that the thickness z, of the stratum at any point, will be that found in art. (287.) + B.

If the second sphere were negatively electrified, B would be negative; and, in other respects, the conclusions would be the same.

(290.) *Let the small sphere receive its fluid by contact with the first, to find the distribution when it is removed to any distance.*

When b is very small compared with a, we have, by art. (266.)

$\frac{\mathrm{B}}{\mathrm{A}} = \frac{\pi^2}{6};\ \therefore$ when $\mu = 1$, or at the vertex of the smaller sphere,

$$z = \mathrm{A}\left\{\frac{\pi^2}{6} - 3\,a^2\right\}, \text{omitting the term in } b.$$

This will be positive, 0 or negative, as $\frac{\pi^2}{6}$ is $>$, $=$, or $< 3\,a^2$.

$$z = 0 \text{ when } \frac{1}{a} = \frac{3\sqrt{2}}{\pi}.$$

Hence if the distance of the centres be to a in a less ratio than $3\sqrt{2} : \pi$, or than 4 : 3 nearly, the fluid at the vertex of the smaller sphere is negative. When the spheres are exactly at that distance, the electrical intensity at the vertex of the smaller one vanishes; and when the distance becomes greater, the electricity at the vertex is positive.

Hence if a sphere of small radius is placed in contact with another sphere electrified, suppose positively, and if we afterwards separate them, the electricity at the vertex of the small sphere, which was 0 at the instant of contact, becomes negative after the separation. It continues so till the distance of the centres becomes $\frac{4a}{3}$ nearly, at which point it is again 0. Beyond this situation the electricity becomes positive, or of the same kind with the other sphere.

(291.) In the case when spheres of any radii are not in contact, the investigation of the distribution of the fluid is more difficult and laborious; and, as we have no series of accurate experiments with which we can compare our results, we shall content ourselves with referring the reader to Mr. Poisson's second memoir on the subject, (*Mém. de l'Instit.* Année 1811, p. 163.) He has there shown how we may obtain the thickness of the electrical stratum at any point of the surface of two spheres, placed within the reach of each other's influence, and under any given circumstances of electrization.

We may observe, however, that a succession of effects at different distances, similar to that described in last article, as occurring when one of the spheres is very small, may occur for other cases: and we have an experiment of Coulomb's of this kind, with which we can compare our calculations.

Coulomb took two spheres, whose radii were as 11 and 4; after placing them in contact, electrifying them positively, and then separating them, he found that the smaller sphere exhibited signs of negative electricity till the distance of the surfaces was equal to the smaller radius: at this distance the electricity of the point on the smaller sphere which was nearest the larger was 0; beyond this it became positive.

In Mr. Poisson's formulæ, if we substitute the values which correspond to the radii of the spheres, and to the position, where the distance of the surfaces is equal to the smaller radius, we find for the electrical thickness on the smaller sphere, A being the mean thickness on the smaller,

$$y = -0.0372\,A.$$

The electricity is negative at the point in question; but so small that it might easily appear insensible.

(292.) From the preceding statements, the reader may be enabled to judge of the agreement between this theory, thus reduced to calculation, and the most careful experiments; and he may decide how far the near coincidence of the natural laws with the mathematical ones establishes the truth of the principles from which the latter are derived. We shall mention one other consequence which follows from the theory, and which agrees with observation, viz. the discharge of a conductor by a *spark*, though, from the nature of the calculations on which it depends, we can only give the results, without going through the investigation on which they depend.

Let, as before, a, b be the radii of two spheres, c the distance of their centres, A and B the mean thicknesses of electricity with which they are charged; and let A′, and B′ be the mean thicknesses of electricity which there would be upon the spheres if they were in contact. Mr. Poisson then finds for the thickness on the nearest point of each sphere, an expression, of which the first term is

$$\frac{2\,(A\,B' - A'\,B)}{(c - a - b)\,\Delta}.$$

Δ is a quantity which involves log $(c - a - b)$. But since $x \log x$ is 0 when x is 0, it appears that if the numerator of the above fraction remain finite, the fraction increases indefinitely, as $c - a - b$ diminishes; that is, as c approaches to $a + b$, or as the surfaces approach to contact. Also the pressure of the electric stratum upon the air which envelopes and confines it is as the square of its thickness. Hence, before the spheres come in contact, this pressure will overcome the resistance of the air which separates them, and the fluid will escape from each to the other, under the form of a *spark*, or in some other way.

This will be the case, whatever be the total quantities of electricity, provided the numerator A B′ − A′ B be but if A B′ − A′ B = 0, the above term will vanish, and there will be no discharge. That is, if

of electricity on the spheres be in the ratio of the charges which they would

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ERRATA.

Page 144, line 9, of art. (239.); on *read* in.
Page 147, line 1; of *read* by.
Page 147, line 2; μ *read* n.
Page 151, line 6, *omit* $= \frac{2}{2n+1}$.
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GALVANISM.

PART I.

GENERAL PRINCIPLES.

1. *Distinction between Galvanism and Electricity.*

(1.) GALVANISM is distinguished from ordinary Electricity, not by any difference in the nature of the agent by which its phenomena are produced, but merely by the mode in which its power is developed and brought into action. It is an error to consider it, as has sometimes been done, as a peculiar species or modification of Electricity: for it has been abundantly proved, as will appear in the sequel, that all the effects produced by Galvanism, are in fact derived from the agency of common Electricity, elicited by particular arrangements and combinations of metallic and other substances, and passing in very considerable quantities, and in a continued current, through the bodies which are placed so as to conduct it, and in which, in consequence of this difference in the circumstances of its transmission, it produces peculiar effects. All the definitions which have been attempted to be given of Galvanism, implying a specific difference in the principle of its action from that of Electricity, are consequently incorrect and fallacious.

(2.) In the account we have already given of Electricity, the facts which strictly belong to that science, and which were known prior to the discovery of Galvanism, have been amply detailed. It has been shown, also, that all these phenomena, however various and complicated they may at first sight appear, are reducible to a small number of general facts, the assemblage of which constitutes the theory of the science. They are principally comprised in the laws of Electric attractions, repulsions, and inductions; in the different conducting powers inherent in different substances, and the mode of distribution of Electricity among the particles of bodies of various forms and in various relative positions. From the law of Electric induction we derive the power of accumulating Electricity in vast quantities, by means of the Leyden jar, and Electric battery, and of obtaining some of its most energetic effects. By the violent action of large quantities of Electricity, thus collected and suddenly transmitted through bodies, we have seen that metals may be fused and volatilized, or reduced to dust, and dispersed in air; that the hardest textures of mineral or organised bodies may be rent asunder, and scattered into fragments; that vegetable and animal life may be destroyed; in a word, that by Electric instruments all the effects of lightning may be imitated, and the walls of the laboratory be made to echo to explosions, which faintly mimic the awful crash and reverberating thunder of the clouds. Such appeared to be the extreme limit attainable by human means in the wielding of so subtle, so universal, and so mighty a power as Electricity,—a power which must rank among the highest of the energies of nature, and which enters as an essential element in all the operations of the material universe.

Part I.

Our knowledge on the subject of Electricity had long been nearly stationary, when a simple fact which was accidentally presented to Galvani, but of which that philosopher at once perceived the importance, laid the foundation of a new science, and gave rise to a series of the most brilliant discoveries which have marked the present age. Great as were the effects of the Electric battery, its power was not susceptible of very advantageous employment as an instrument of delicate analysis, although it had occasionally been available as an agent for effecting combinations, and other changes of composition among gases. Its action, although sufficiently energetic, was but momentarily exerted; the power ceased the very instant after it was brought forth, and could not be recalled but by the slow and laborious repetition of the process by which it had been collected. The science of Galvanism has put us in possession of an instrument of incomparably greater power, and capable of the most extensive application in various analytical researches, and in various branches of physical science. The same power, which in the highly charged Electric battery is lavished and dissipated by a single discharge, is developed in great abundance in the Voltaic battery; and far from being rapidly expended, continues to be poured forth in profusion for an indefinite time, and may be directed at pleasure so as to produce different changes of composition, and other affections of bodies subjected to its action. The Vôltaic apparatus, in its most active state, may be regarded as a vast magazine of Electricity, capable of furnishing a continued supply for a very long period, at the demand of the experimentalist, and placing this mighty agent entirely under his controul. This instrument has opened a new field to the cultivators of science, and a rich harvest of discoveries has already rewarded their exertions.

Galvanic effects.

(3.) Although no doubt can be entertained of the identity of the powers which are derived from the Voltaic and Electric batteries, yet it does not appear that the phenomena of Galvanism were capable of being deduced from the previously known laws of Electricity: of which laws we have already traced the more important combinations and consequences; and of which we have furnished the mathematical formulæ by which even their most complicated results may be calculated. Thus it would not have been possible, from the consideration of the laws of Electric equilibrium, to have foreseen that any disturbance of the

Sources of Electricity,

And of Galvanism.

equilibrium would have resulted from those arrangements of certain bodies which constitute the different forms of the Galvanic circle. It must be confessed, indeed, that the theory of Electricity, in every thing that relates to the sources of its original excitation, is still exceedingly deficient. In the seventh Chapter of our Treatise on ELECTRICITY, (p. 119,) the several processes by which Electrical properties are developed are discussed, and are arranged under seven different heads: namely, friction of various kinds; processes connected with the exercise of the functions of animal life; changes of temperature; meteorological changes occurring in the atmosphere; evolution of gaseous matter, or its condensation into a liquid or a solid; the separation of the particles of a solid body united by cohesion; and pressure applied to crystalline bodies in particular directions. But these are not all the sources of Electricity. It was then stated that the consideration of the Electricity which is developed by the mere contact of metals was purposely omitted, being reserved for that branch of the subject which we are now investigating. But there is also another source of the developement of Electricity, intimately connected with all the phenomena of Galvanism, namely, the chemical action of bodies on each other. It is indeed probable, as was remarked in the section relating to the developement of Electricity during evaporation, that no chemical change can take place among the elementary molecules of bodies, without the production of some corresponding change in the Electric condition of those bodies, although such change may often not admit of being detected or appreciated. On these two circumstances; namely, the disturbance of Electric equilibrium by the contact of dissimilar metals, and the evolution of Electricity by chemical action, are the whole of the phenomena of Galvanism dependent. But as the theory by which these phenomena are connected and generalized, cannot be understood until the facts themselves have been studied, our first business must be to give an account of these facts, arranging them, for the sake of convenience, under their appropriate heads. We shall then be prepared to inquire into the theoretical reasonings to which they have given rise, and the different hypotheses which have been devised for their explanation. We shall conclude by presenting a brief sketch of the history of the science, in which the principal discoveries will be reviewed in the order in which they were successively made by their respective authors: for we conceive that much greater interest will attach to such a review, as well as more instuction be derived from it, when the reader has already been made familiar with the subject, and is therefore capable of appreciating the relative importance of the facts it embraces, and of assigning to each discoverer the merit that is due to him.

2. *Elements of Galvanic combinations.*

(4.) Our attention is first to be directed to the general outline of the principal phenomena of Galvanism, as they are most usually presented to our observation. We shall begin by studying these phenomena in their simplest state, or greatest degree of generalization. We shall thus arrive most readily at the knowledge of what are the circumstances belonging to the Galvanic arrangements of bodies which are essential to the production of those particular effects. For this purpose we shall select such combinations developing Galvanic Electricity, as are the simplest possible. The elements of all Galvanic combinations are necessarily three in number, and it is essential to their action that they be arranged so as to compose a circle. Of these three elements one at least must be a fluid, and another must be a solid body; the third may be either a solid or a fluid, according to circumstances; but we shall, for the present, consider only the case in which the circle is constituted by two solids, and one fluid body. It is essential that the two solid parts be conductors of Electricity in a very eminent degree, and that they shall consist of different kinds of substance; and that the fluid part of the circle be capable of exerting a chemical action upon one of these solids. Thus, if a plate of zinc be in contact with a plate of copper at one of their extremities, and if in this state they be both immersed in a diluted acid, so that the zinc, the acid, and the copper all touch one another, a Galvanic circle is constituted, and the following Electric movements will take place. There will be a current of vitreous, or positive Electricity, passing from the zinc to the acid; from the acid to the copper; and from the copper to the zinc: while, on the other hand, a current of resinous or negative Electricity will circulate in the opposite direction; that is to say, will pass from the zinc to the copper; from thence to the acid; and from the acid to the zinc; and so on in a continued stream. The arrangement here described is represented in fig. 1, where Z and C are sections of the zinc and copper plates, which are in contact at their upper edges, and of which the lower ends are immersed in the diluted acid, A; the direction of the positive Electric current above and below, being indicated by the position of the arrows.

Part

Galva circles

Simple

Fig. 1.

(5.) If, while the two metals are immersed in the acid, they be removed from each other, as represented in fig. 2, so as to be no longer in immediate contact; and a communication be established between them by means of a metallic wire, W X, bent so as to form a considerable arch, and touching each of the metals respectively at p and n, a Galvanic circle will, in like manner, be formed; the circuit of opposite Electricities taking place, as before, from one plate of metal to the other; through the fluid, on the one hand; and through the connecting wire, on the other. The direction of the stream of positive Electricity is that denoted by the arrows; namely, in the fluid, from the zinc towards the copper; and in the wire, from the copper to the zinc. The current of negative Electricity must, of course, be understood to flow in a direction exactly the reverse. The most convenient mode of interrupting or renewing at pleasure the Galvanic circuit is to have, in place of a single wire extending from one metal to the other, two separate wires, W, X; one affixed to each of the metals, at one end, while by their other ends w, x, they may be made to touch or to separate from one another.

Fig. 2.

(6.) The intensity of the Electricity elicited by such an arrangement, will be increased by a repetition of the same combination in regular succession. The apparatus will then have the form represented in the section fig. 4; in which the zinc and copper plates, denoted as before by the letters Z and C, are combined in pairs, being connected at their upper edges by slips of metal passing from the one to the other. They are immersed into a corresponding number of

Comp

Fig. 4.

separate vessels, containing the diluted acid; so that the two plates belonging to each pair shall be contained in two different, but adjoining vessels of the series; and care being taken that the same order of alternation of the metals be observed. Each vessel will thus contain one plate of zinc and one plate of copper, which, as they belong to different pairs, are not connected, and which must not come into contact with one another. To an arrangement of this kind, in which Volta employed a circular series of cups to contain the fluid, he gave the name of *Couronne de tasses.*

In order to obtain a similar apparatus in a more compendious form, the plates are brought nearer to each other by employing troughs of mahogany, divided into cells by glass partitions, or what is still more convenient, troughs made of Wedgwood ware, with the partitions of the same material. The plates of zinc and copper are soldered together in one point only, and each pair of plates is arranged so as to enclose a partition between them; there is consequently in each cell a copper plate connected with the zinc of an adjoining cell, and so on in regular succession. The troughs usually contain ten or twelve pairs of plates, and these are connected together by a slip of baked wood, so that they may be lifted out of the cells together, see fig. 7. One advantage of this construction is, that the fluid may remain in the trough, while the action is suspended by lifting the plates from the cells; and another is, that the plates are easily replaced when worn or injured. It has been ascertained by Dr. Wollaston, that the power of a battery upon this construction is increased at least one half, by adding another copper plate to each member of the series; so that every cell will contain one zinc and two copper plates, and each surface of zinc is opposed to a surface of copper: for, in the usual arrangement, although both sides of the zinc are oxidated, that side only is efficient which has a copper surface opposed to it.*

(7.) It will necessarily follow from the arrangements now described, that except in the case in which, as in the *couronne de tasses*, the vessels are placed in a circle, so as to form a recurring series, having properly neither beginning nor end, the plates at the two extremities of the series will not be received in any of the vessels, and therefore will not be in contact with any fluid; and as they will also, in this case, be at a distance from one another, it will be necessary to employ wires, or other metallic media of communication between them, in order to establish the Galvanic circuit. The directions of the currents of Electricity will here be the same as in the case of the simple arrangement of fig. 2, and are pointed out by the position of the arrows in the figure.

(8.) Another form of construction for the Voltaic battery is the one invented by Mr. Cruickshanks, represented in fig. 6, in which Z, C, Z, C, &c. represent sections of pairs of plates of zinc and copper, soldered together at their adjacent surfaces, arranged so that all the zinc plates shall be on the same side, and all the copper plates on the other, and fixed to the sides of a trough of baked wood, which is a non-conductor of Electricity, with intervals between them, such as that by means of the sides of the trough cells may be formed between each pair of plates, capable of containing a fluid. When these cells are filled with acid, and a communication between the two extremities of the battery is made, by bringing the ends of the wires, W, X, in contact with one another, the Galvanic circle is completed, and the usual currents are established.

Pile of Volta.

(9.) What has been termed the Voltaic pile, from the name of its discoverer, Volta, is an arrangement of precisely the same kind as the former, the series being arranged vertically instead of horizontally; the metallic part being composed of circular discs of zinc and copper arranged in pairs; and the fluid portion of the series consisting of pieces of some substance of spongy texture, such as card or linen, moistened with the liquid to be employed, which we have here supposed to be diluted acid. The column thus constituted, and which is represented in fig. 5, either sustains itself by its own weight, or may be supported by a frame of glass rods, fixed vertically around it. The circuit will now require to be completed by forming a communication between the upper and lower plate by any conducting medium, such as the wire W.

Fig. 5.

(10.) It will be evident, upon a little consideration, that however the two modes of arrangement which we have last described, namely those exhibited in fig. 5 and 6, may appear to differ from the preceding one, represented by fig. 4, they are, in fact, all essentially the same. The principal difference between them, and it is a difference merely of form, consists in the connection between the copper, which is in contact with the fluid of one cell or vessel, with the zinc which is in contact with the fluid in the next cell or vessel, being made in the one case by means of a slip of metal extending from the one to the other; while in the other case it is affected by the actual junction of the two plates by the whole of their adjacent surfaces.

As we are at present occupied only with general views of the subject, we refrain from entering into any details concerning the particular construction of the various kinds of apparatus formed upon the preceding models, or concerning the relative advantages of each for particular purposes of inquiry. The subject will be resumed in the sequel, when the objects of the construction, and the reasons for which they have been adopted, can be better appreciated. It will be sufficient for our present purpose to observe, that in order to obtain the effects which we are about to describe, it is requisite that a sufficiently large surface of the metals be exposed to the action of the fluid, and that the oxidation of the zinc should proceed rapidly; it is also necessary for the exhibition of many of these effects, that the alternations of the series of the metals and fluids should be numerous.

Denomination of the poles of simple Batteries.

(11.) There is one circumstance of considerable importance, that deserves attention in studying the properties of these Galvanic instruments. It may be observed, that every Voltaic battery, or combination calculated to produce Galvanic Electricity, is referable either to the class of the simple, or of the composite battery. The first consists of a single ternary arrangement of the elements of the battery, as we have described §. 4 and 5, and illustrated by fig. 1 and 2. Each end of the communicating wire, by which, in the second of these cases, the circuit is completed, has a direct metallic communication with the whole of the metallic surface acted upon by the fluid, on its respective side. In all these instances no ambiguity can arise as to the denomination of the two sides of the battery, with reference to the metals which are situated on those sides. The end of the wire in communication with the zinc must be designated the zinc side of the battery; and, in like manner, the end of the wire adjoining to the copper will be the copper side. As in this form of the battery the stream of positive or vitreous Electricity is found to issue from the copper side, and to be received by the zinc side of the battery, through the medium of the wire; while the reverse is to be understood as the course of the negative or resinous Electricity; so the copper side must be designated as the positive end or pole of the battery, and the zinc side as the negative end or pole.

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* *Annals of Philosophy*, vi. 209; and *Philosophical Transactions for* 1815, p. 363.

Dr. Hare's Calorimotor.

(12.) A battery on a large scale, constructed upon this model, that is, consisting essentially of only one sheet of zinc, and one of copper, formed into coils, is often denominated a *Calorimotor;* a name given to it, for reasons which will hereafter be explained, by Dr. Hare of Philadelphia, who constructed a very powerful instrument of this kind. The zinc sheets were about nine inches by six, the copper fourteen by six; more of the latter metal being necessary, as in every coil it was made to commence within the zinc, and completely to surround it without. The sheets were coiled so as not to leave between them an interstice wider than a quarter of an inch. Each coil was about two inches and a half in diameter; their number amounted to eighty; and by means of a lever, they were made all to descend together into eighty glass jars, two inches and three quarters diameter inside, and eight inches high, properly placed to receive them.* Fig. 8 shows the horizontal section of one of these coils.

Fig. 8.

Battery of London Institution.

(13.) The apparatus belonging to the London Institution, and which was constructed under the direction of Mr. Pepys, belongs also to this class. It consists of only two plates, the one of copper, and the other of zinc, coiled round a cylinder of wood, with ropes of horse hair interspersed between them, in order to prevent their being in contact with one another. Each plate is fifty feet in length, and two feet in width, making a total surface of 400 square feet. When its action is required, the whole coil is immersed in a tub containing acid.†

(14.) The more usual forms of Voltaic batteries are those which belong to the second, or composite class, and consist of a certain number of alternations of the ternary series of elements. Of these we have seen examples in the Voltaic pile, fig. 5; in the trough battery, fig. 9; and in the common plate battery, fig. 7. The battery of the Royal Institution, which consists of 200 separate parts, each part composed of ten double plates, and each plate containing thirty-two square inches, may be taken as an example of a very powerful instrument constructed upon this last model. The whole number of the double plates is 2000, and the whole surface 128,000 square inches.

(15.) It will be recollected, that in all these instances the metallic plates, which terminate the series at either end, are not in contact with any portion of the fluid in the battery; but are, on the contrary, in contact with a metallic plate of a different kind. Now the currents of Electricity in each fluid portion of the apparatus, pass between the surfaces of the metals that are separated by that fluid, in the same directions as in the single combination formerly described; that is, the positive Electricity flows from the zinc, through the fluid, to the copper. But the last copper plate has a plate of zinc attached to it, which is the last plate in the series on that side. The positive Electricity received from the fluid by the copper, will be transferred to the zinc plate, and by the zinc to the communicating wire on that side. It follows, therefore, as a necessary consequence, that the zinc end is the positive pole of the battery. The same mode of reasoning applied to the opposite current of negative Electricity, which flows from the copper, through he fluid, to the zinc, and thence to the terminal plate of copper, and the wire, which is continuous with it, will show that this copper end will be the negative pole of the battery. It will be perceived, that this is just the reverse of what takes place in the simple battery, or *calorimotor,* in which it is the copper end that is positive, and the zinc end that is negative. Inattention to this circumstance has often been productive of much ambiguity in describing experiments, and in reasoning upon their results. The accurate distinction between the positive and negative poles of the battery is more especially to be kept in view in experiments on Electro-Magnetism, where the direction of the tangential Magnetic force depends altogether upon the direction of the Electric currents in the communicating wire.

The account which has now been given of the nature and different modes of arrangement of the component parts of Galvanic circles, and of the direction of the Electric currents, of which they occasion the rapid circulation, will be sufficient to prepare us for the consideration of the effects they produce on various bodies exposed to their action.

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* Silliman's *Journal,* iii. 105; and *Annals of Philosophy,* New Series, i. 330.

† *Philosophical Transactions for* 1823, p. 187.

PART II.

THE EFFECTS OF GALVANISM.

Part II.

(16.) We purpose treating of the effects produced by Galvanism under the following heads: namely, 1st, the ordinary and purely Electrical effects of attraction, repulsion, and induction; 2dly, those attended with evolution of light and heat; 3dly, Electro-Magnetic effects; 4thly, chemical changes of composition; and 5thly, physiological effects.

CHAPTER I.

Effects purely Electrical.

(17.) The Electricity acquired by any conducting substance in a state of insulation, by previous contact with the prime conductor, or the rubber of the common Electrical machine, exists in that body in a very different state from the Electricity which is evolved by the different parts of the Voltaic battery. The former manifests its presence by various positive and striking indications. A conductor so charged will attract light bodies in its neighbourhood, and after imparting to them, by contact, a portion of its Electricity, will, in the next place, repel them to a distance. The divergence of the electrometer points out the degree of intensity of the Electricity under these circumstances, and indicates its high state of elasticity and mobility, or tendency to diffuse itself to the surrounding bodies capable of receiving it. On the other hand, the indications of the presence of Electricity at the extremities, or in any part of the Voltaic battery, even when the circuit is interrupted, by the separation of the wires which form the connection between them, are comparatively feeble; although the quantity of Electricity which is really developed, may be exceedingly great. But when the circuit is completed, and while the whole of this Electricity is in rapid circulation, the electrometer gives no indication of its presence.

The attraction of unelectrified, or of dissimilarly electrified bodies, and the repulsion of similarly electrified bodies, are among the most unequivocal and decisive tests of the agency of Electricity. But from a single combination of plates, such as that of the Calorimotor, no effect of this kind can be obtained, unless electroscopes of very extraordinary sensibility be employed. With electrometers of the usual construction, no sensible Electricity can be discovered to exist, either in the zinc or copper plate when separated by an acid solution, whatever extent be given to their surfaces in contact with the acid. When a few alternations of plates and interposed fluid are employed, either in the Voltaic pile or battery, Electrical appearances may be detected by means of the condenser; and the opposite extremities are found to be in different states of Electricity. With a series of fifty groups, a delicate gold-leaf electrometer will be affected, without the aid of the condenser. With one hundred pairs, the divergence of the gold leaves is sufficiently distinct; and with a series of one thousand groups, even pith balls are made to diverge. In these experiments, a wire proceeding from one extremity of the battery, is to be connected with the foot of the electrometer, whilst a wire proceeding from the opposite extremity is brought to touch its cap. The Electricity of the zinc side is always positive, that of the copper side always negative.* The ends of the wires which communicate with the two poles, being in opposite Electrical states, will be found, when they are brought together, to attract one another.†

By means of a condensing electroscope of extreme sensibility, invented by M. Bohnenberger, and since adapted to this particular object by M. Becquerel, the latter has ascertained, that even in a single pair of plates of zinc and copper, not in contact with each other, but only immersed in an oxidating fluid, the zinc plate gives indications of negative Electricity, and the copper of positive Electricity; a result which, although apparently contrary to that which obtains in the composite battery, is yet perfectly accordant with the same species of Electric currents in the fluid in both cases, and is indeed, as has been already explained, the necessary consequence of the peculiar arrangement of the plates.‡ The nature of the Electricity of the ends of the composite battery was first ascertained by Messrs. Nicholson and Carlisle, with the instrument called the Revolving Doubler.§

Induction from Galvanism.

(18.) Induction is one of the characteristic effects of Electricity, as well as attraction and repulsion; and the most remarkable of the results of induction is seen in the capacity of accumulation which the Leyden jar and Electric battery possess. Now the Electricity derived from Galvanism, is equally capable of being accumulated in those instruments, as the Electricity obtained in the common Electrical machine. If wires proceeding from each extremity of the Voltaic battery, be respectively connected with the inner and outer surfaces of an Electrical battery, of not less than twelve square feet of coated surface, the latter will be instantly charged, and all the usual Electrical experiments may be performed with it in this state, when removed from the Voltaic battery. If the discharge be made, and the same communications be renewed, it will again immediately receive a similar charge of Electricity; and the same will happen after an indefinite number of discharges. If, instead of removing the Electrical battery, its connection with the Voltaic battery be still continued, sparks may be obtained from it in rapid succession, by connecting a wire with the outer coating, and repeatedly striking the knob with the other end of the wire. These sparks are so strong when the charge is communicated by a series of three or four hundred alternations, that the end of wire, if it be of iron, is made to scintillate, or throw off abundance of its own particles in a state of intense combustion. With a series of one thousand, the sparks are attended by a distinct crackling noise, and have sufficient power to burn thin metallic leaves. This is the more remarkable, as the Voltaic battery, from which the Electric battery has derived its power, may itself be too weak to produce this effect.* It always happens, indeed, that a single jar is charged by contact with a Voltaic apparatus, in which the fluid consists merely of water, to a degree of intensity rather greater than that of the apparatus itself; and it will consequently affect an electrometer somewhat more distinctly. In all cases the full charge is communicated by the shortest possible contact with the Voltaic battery. In the experiments made by Van Marum and Pfaff, a battery having $137\frac{1}{2}$ square feet of coated surface was charged to the same degree of tension, as the pile with which it was made to communicate, by a contact which did not last for the twentieth part of a second.†

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* Singer's *Elements of Electricity and Electro-Chemistry*, 329.

† Biot, *Traité de Physique*, ii. 511.

‡ *Annales de Chimie*, xxv. 405.

§ Nicholson's *Journal*, 4to, iv. 174.

CHAPTER II.

Evolution of Light and Heat by Galvanism.

1. *Luminous appearances.*

Spark.

(19.) The transit of any considerable quantity of Electricity through the air is, as we have seen in the Treatise on Electricity, always attended with the evolution of light; and, generally, in the form of a spark or luminous train. A similar appearance is observed during the transit of Galvanic Electricity, if the intensity be sufficient for that purpose. It is very readily obtained in a Voltaic battery composed of a considerable number of alternations of plates, when the communication between the two extremities is made by metallic wires. At the moment of contact a distinct spark is perceived, which occurs every time the contact is alternately broken and renewed. But the most striking effect of this kind is produced by placing pieces of charcoal, shaped like a pencil, at the two ends of the wires in the interrupted circuit, and bringing their points into contact. The appearances, when the experiment was tried with the powerful battery of the Royal Institution already noticed, were singularly beautiful. When the pieces of charcoal were brought within the thirtieth or fortieth part of an inch of each other, a bright spark was produced; and at the same time more than half the volume of the charcoal, which was about an inch long, and one-sixth of an inch in diameter, became ignited to whiteness. By withdrawing the points from each other, a constant discharge took place through the heated air, in a space equal at least to four inches, producing a most brilliant arch of light, of considerable breadth, and in the form of a double cone. This phenomenon is represented in fig. 3, in which W, X are the conducting wires communicating with the ends of the battery; C, C the pieces of charcoal; and A the luminous arch of Electrical light, making the transit of the Electricity through the air. When any substance was introduced into this arch, it instantly became ignited; platina melted as readily in it as wax in the flame of a common candle; quartz, the sapphire, magnesia, lime, all entered into fusion; fragments of diamond, and points of charcoal and plumbago, rapidly disappeared, and seemed to evaporate in it, even when the connection was made in a receiver exhausted by the air pump; but there was no evidence of their having previously undergone fusion. When the communication between the points positively and negatively electrified was made in air, rarified in the receiver of an air pump, the distance at which the discharge took place increased as the exhaustion proceeded; and when the air in the vessel supported only one quarter of an inch of mercury in the barometrical gage of the air pump, the sparks passed through a space of nearly half an inch; and by withdrawing the points from each other, the discharge was made through six or seven inches, producing a most brilliant coruscation of purple light, while the charcoal itself became intensely ignited, and some platina wire attached to it fused with bright scintillations, and fell down in large globules.* These phenomena may be exhibited on a smaller scale, by means of a hundred pair of plates of six inches square; an apparatus which is well suited for all experiments of fusion and ignition. The arched form of the stream of light passing between two charcoal points, is often very perceptible when the distance of the points does not exceed half an inch. Charcoal made from some of the harder woods, such as beech, lignum vitæ, or boxwood, is the best for these experiments, and it should be carefully prepared.

Arch of light.

Fig. 3.

(20.) The light thus evolved by the contact and recession of charcoal points, forming part of the circuit of Voltaic Electricity, is more vivid and intense than any other that can be produced by art. It often exhibits all the variety of the prismatic colours. When the battery is powerful, the emission of light may be kept up for a considerable time; it is so dazzling as to fatigue the eye even by a temporary glance, and effaces by its superior lustre the light produced by lamps in an apartment otherwise brilliantly illuminated, and which, on the sudden cessation of the Galvanic light, appears for a short time as if left in darkness. It is a light which so nearly emulates the brightness of the sun's rays, as to be applicable for the purposes of illuminating objects in a solar microscope; and it has been applied by Mr. Allen in his Lectures, to the exhibition, on a large scale, of the appearances in the kaleidoscope, by the magic lanthorn.

It is observed by Mr. Singer, that the light thus obtained appears to be derived principally from the immediate action of the Voltaic Electricity, and not from the combustion of the charcoal; for although the charcoal be at the same time in a state of ignition, yet it is found to suffer but little waste. The light is evolved with equal splendour when the experiment is made in gases that contain no oxygen, such as azote or chlorine, and in which, therefore, combustion could not be maintained; it is found, indeed, that no change takes place either in the gas or the charcoal in these experiments.† Light is also obtained, though with diminished intensity, under water, alcohol, ether, oils, and other fluids of imperfect conducting power.

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* Singer, p. 331.

† *Annales de Chimie*, xl. 289.

* Davy's *Elements of Chemical Philosophy*, p. 152—154.

† Children, *Philosophical Transactions for* 1815, p. 369.

2. *Ignition, Fusion, and Volatilization.*

(21.) The transit of Electricity which takes place in the discharge of the Electric battery, and even the spark from the prime conductor of the machine, at the same time that it gives out light, is attended with the evolution of heat, though in a degree far inferior to that which takes place during the continued discharge of the Voltaic battery. But there is also this more remarkable difference between the operation of the two instruments. The common Electrical apparatus never exhibits any effect of heat, unless when the restoration of Electric equilibrium is suddenly performed, an event which is always accompanied with the appearance of light: and it may even be questioned, whether the rise of temperature which then takes place, be not attributable rather to the mechanical concussion which the particles sustain during this violent action, than to any direct property which is due to the Electricity of producing heat. In the Voltaic apparatus, on the other hand, an elevation of temperature is observed to take place, when the circuit remains complete, and when no light is evolved. The mere passage of Voltaic Electricity through conducting bodies, raises their temperature; and when the apparatus is powerful, and the size and nature of the conductors proportioned to the quantity of Electricity to be transferred, the most intense ignition is produced in them.[*] If a fine iron wire of moderate length be made the medium of connection between the extremities of the battery, it becomes ignited, and may be fused into balls. Steel wire, under the same circumstances, burns with a brilliant and rapid combustion. If a platina wire be employed, it may be kept at a red or even white heat, for an indefinite length of time. There appears to be no limit to the continued evolution of heat, so long as the battery preserves its power. These effects appear to be those of an abundant and inexhaustible stream of Electricity, flowing in an equable and continuous current, and producing no other change in the metal through which it passes, than merely raising its temperature. It never produces its sudden and violent dispersion into fragments, as happens with the explosive discharges of an Electric jar.

(22.) An elegant mode of exhibiting the production of heat, by the passage of Voltaic Electricity through a metallic wire, is to make the wire pass through a known quantity of water, contained in a vessel in which a thermometer is placed. As soon as the wire is made to form a part of the Voltaic circuit, the thermometer will be seen to rise, and rapidly advance to the boiling point; after which the ebullition continues with great steadiness. The time required for raising the water to the temperature of ebullition, or the quantity evaporated during a certain time, will afford tolerably accurate modes of estimating the quantity of Electricity that has passed through the wire.

(23.) Inflammable bodies, such as oils, alcohol, ether, and naphtha, are easily inflamed, when charcoal points in the circuit of the battery are ignited by it, and brought near each other on the surface of these fluids. Gunpowder, under the same circumstances, may readily be made to explode. The order in which metallic wires are raised to a red heat by the action of Galvanism was ascertained by Mr. Children, who employed for that purpose a very powerful apparatus of his own construction, to be the following; viz. platina, iron, copper, gold, zinc, and silver. Between gold and copper the difference is trifling; and with regard to platina and iron, their relations to each other, in this circumstance, seem to be affected by elevation of temperature. These results were obtained by comparing together in each experiment two wires of dissimilar metals, but of equal diameter and length, (one end of each being in communication with one of the poles of the battery, and the other end bent to an angle,) and connected continuously by hooking them together. The length of each wire was eight inches, and the diameter one-thirtieth of an inch. The results were the same to whichever pole of the battery either wire was presented. The places which tin and lead should have occupied in the scale of capability of being heated by Galvanism, could not be ascertained in these experiments, because they melted before they acquired a red heat. Since it appeared that the facility with which the metals were ignited, varied inversely as their conducting power for Electricity, it was inferred by Mr. Children, that the degree of resistance to the passage of the Electric current, was the circumstance that occasioned the developement of heat in all these instances. But the fact that the greatest heat is produced in air, where there is reason to suppose the least resistance, is, as Sir H. Davy observes, in opposition to this theory. A beautiful illustration of the difference which exists in metals as to their capacity of ignition, is to place in the Voltaic circuit a wire or chain composed of alternate portions or links of platina and silver soldered together; when the silver links are not sensibly heated, but all those of platina become equally and intensely ignited.

Effects of Mr. Children's battery.

(24.) The following are among the most remarkable of the effects of Mr. Children's battery in producing heat. Five feet and a half of platina wire rather more than one-tenth of an inch in diameter was raised to a red heat, visible in full daylight. A similar effect was produced upon a bar of platina one-sixth of an inch square and two inches and a quarter long, and the end of it was melted. Several substances esteemed the most refractory were fused by the action of this battery. The oxide of molybdena was readily fused and reduced; the oxide of tungsten was also fused, and partially reduced; the oxides of uranium, titanium and cerium were fused, but not reduced; and the oxide of tantalium was only partially fused. All these metallic oxides, previous to their being subjected to the Galvanic action, had been intensely ignited in a charcoal crucible, in a powerful furnace. The compound ore of iridium and osmium was fused into a globule; and iridium was formed into a globule containing small cavities. By heating iron in contact with diamond powder, the diamond was consumed, and the iron converted into perfect blistered steel. Blue spinell and gadolinite were fused, and zircon from Norway imperfectly so. Magnesia was agglutinated; while ruby, sapphire, quartz, and silex, were not affected.[*] It would appear, therefore, that the heat produced by the Voltaic battery is more considerable than has hitherto been obtained by any other process.

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[*] See Cuthbertson, in Nicholson's *Journal*, viii. 97.

[*] *Philosophical Transactions for* 1815, p. 368—370.

3. *Deflagration.*

Combustion of Metals.

(25.) Another mode in which the production of heat by the Voltaic battery is exhibited by very striking effects, is to direct its action on the metals beat out into very thin leaves. When these leaves are made the medium of communication between the poles of a powerful apparatus they take fire, and by continuing the action, may be made to burn with great brilliance. These effects are best obtained by suspending the metallic leaves to a bent wire proceeding from one extremity of the battery, and to bring in contact with them a broad metal plate connected with the opposite extremity. By covering the plate with gilt foil, the brilliancy of the effects is still further increased. Gold leaf, treated in this way, burns with a vivid white light tinged with blue, and produces a dark purple or brown oxide. Silver leaf emits a brilliant emerald green light, and leaves an oxide of a dark grey colour. Copper produces a bluish white light, accompanied by red sparks; its oxide is dark brown. Tin exhibits nearly the same phenomena, but its oxide is of a lighter colour. Lead burns with a beautiful purple light; and zinc with a brilliant white light, inclining to blue, and fringed with red. For the distinct appearance of these colours it is essential to make the contacts with metal; for if charcoal be used, the vivid white light it emits effaces the colours produced by the combustion of the metal.*

Van Marum noticed a beautiful effect which took place when a slender iron wire was connected with one extremity of a powerful battery, and its end brought to touch the surface of some mercury connected with the other extremity. A vivid combustion both of the wire and the mercury was produced. Sparks were dispersed in profusion on every side, forming thousands of rays, as if proceeding from a star or sun of considerable diameter. This splendid spectacle may be continued at pleasure, by gently depressing the extremity of the iron wire, in proportion as the metallic particles are dispersed by the combustion.

4. *Effects contrasted with those of Electricity.*

Difference of effects from those of Electricity.

(26.) The effects which we have been describing as those of the Voltaic battery are highly instructive, as demonstrative of the vast quantity of Electricity evolved by the instrument; and they are also strikingly contrasted, in many essential circumstances, with those produced by the Electric battery. The violence with which the whole of the charge, in the case of the latter instrument, is instantaneously forced, as it were, through the substances which lie in its passage, produces all the effects of a powerful mechanical concussion. The heat which may occasionally appear to be evolved, seems to be merely a remote consequence of the forcible compression and collision of the particles of the body during the momentary transit of the Electricity. The passage of Voltaic Electricity, on the contrary, seems to produce, as one of its immediate and direct effects, an elevation of temperature, while the mechanical texture of the substance remains unchanged. Hence, whatever igniting power may be possessed by common Electricity, it is transient and scarcely perceptible, and its tendency is rather to separate and disperse the particles of bodies, than to unite them into globules by fusion. Charcoal, which is a substance most readily ignited by Voltaic Electricity, sustains a powerful discharge of common Electricity without its temperature being sensibly raised. Dr. Hare endeavoured in every mode he could devise to ignite charcoal by common Electricity, but without success. Exposed to the discharge of a powerful battery in pieces tapering to a point, in a glass tube, in thin strips, and in powder, by means of the apparatus usually employed for inflaming ether, it was either uninfluenced, or merely dispersed, without the smallest symptom of ignition, or even of increased warmth. Yet the same discharge was sufficient to cause the explosion of fulminating mercury, placed under the same circumstances as the powdered charcoal in the former experiment; thus clearly showing that its action was by mechanical concussion. We have seen that water is easily made to boil by immersing in it a wire which forms part of the Voltaic circuit. But in Dr. Hare's experiments, pointed wires, covered with spermaceti, and exposed to a current of Electricity from a fine plate machine of thirty-two inches diameter, exhibited no sign of fusion: nor was a differential thermometer, filled with ether, according to Dr. Howard's plan, affected sensibly, though the warmth of a finger applied to the bulb, caused the fluid in the stem to move nearly a foot. When a spherule of lead suspended by a slender filament of the same metal to one of the poles of Dr. Hare's Calorimotor, was made to communicate with the other pole of the instrument, the spherule was instantaneously fused, yet the filament, which was fifty times smaller, remained uninjured. The contrary happens when a similar mass of lead suspended by a filament is made the medium of discharging an Electrical battery; in this case the filament is destroyed, but the spherule remains unchanged.*

5. *Circumstances on which the Igniting Power depends.*

Ignitin power.

(27.) In all metallic wires the capability of being ignited by a Voltaic battery is altogether dependent, not upon the intensity of the Electricity developed, but upon the quantity which is transmitted by the wire. It has reference, therefore, not so much to the number of alternations of plates of which the apparatus is made to consist: but to the total extent of the surfaces producing Galvanism. In instruments of similar construction, but differing in their magnitude, we should expect similar results, provided the same proportion were preserved between the extent of surface in the battery, and the area of the transverse section of the wire. The experiments of which we have lately stated the results, were made with large and powerful instruments; but it is evident that if the same relations of its parts were adhered to in a battery of the smallest dimensions, the same effects would be obtained. Dr. Wollaston occupied himself, about the year 1812, in making a series of experiments for the purpose of ascertaining the most compendious form of apparatus by which visible ignition might be produced. After several trials he found that a single plate of zinc one inch square, when properly mounted, is more than sufficient to ignite a wire of platina one three-thousandth of an inch in diameter, even when the acid employed is very dilute. The smallest battery that he constructed consisted of a thimble, without its top, flattened till its opposite sides were about one-fifth of an inch as under. The bottom part was then nearly one inch wide, and the top about eight-tenths; and as its length did not exceed nine-tenths of an inch, the plate of zinc to be inserted was less than three quarters of a square inch in dimensions. Previously to insertion, a little apparatus of wire, through which the communication was to be made, was soldered to the zinc plate, and its edges were then coated with sealing wax, which not only prevented metallic contact at those parts, but also served to fix the zinc in its place by heating the thimble so as to melt the wax. A piece of strong wire, bent so that its two extremities could be soldered to the upper corners of the flatted thimble, served both as a handle to the battery, and as a medium to which the wires of communication from the zinc could be soldered. The conducting apparatus consisted in the first place of two wires of platina, about one-fortieth of an inch in diameter, and one inch long, cemented together by glass in two parts, so that one end of each wire was united to the middle of the other. These wires were then tinned, not only at their extremities, for the purpose of being soldered to the zinc and to the handle, but also in the middle of the two adjacent parts, for receiving the fine wire of communication. One inch of silver wire, one-hundredth of an inch in diameter, containing platina at the centre one-thirtieth part of the silver in diameter, was then bent so that the middle of the platina could be freed of its coating of silver by immersion in dilute nitrous acid. The portion of silver remaining on each extremity served to stretch the fine filament of platina across the conductors during the operation of soldering. A little sal ammoniac being then placed on the points of contact, the soldering was effected without difficulty, and the two loose ends were readily removed by the silver attached to them. When the fine platina wire was reduced to the length of between one-thirtieth and one-fiftieth of an inch, it was readily ignited by immersing this miniature battery in water containing only one-fiftieth part of sulphuric acid. Though the ignition effected by so dilute an acid be not permanent, its duration for several seconds is sufficient for exhibiting the phenomenon, and for demonstrating that it does not depend upon mere contact, from which only an instantaneous spark should be expected.*

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* Singer, p. 409; and *Philosophical Magazine.*

* *Annals of Philosophy,* New Series, i. 339.

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(28.) The length of wire ignited by the Voltaic battery, as well as the intensity of the ignition, will, as we have already remarked, be proportioned to the quantity of Electricity which that wire transmits in a given time. This will depend upon several circumstances; some of which affect the powers of the battery; others have reference to the capacity of transmission in the wire; and others, again, relate to the proportion between these different powers. The estimation of effects resulting from so great a complication of causes is, therefore, in many cases, very difficult; and the more so, because the influence of some of these circumstances has not yet been ascertained with any precision.

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(29.) The powers of the Voltaic battery, it is reasonable to presume, increase with the number of plates it contains, at least within certain limits; but the ratio of increase, as well as the limits of that increase, appear to be, in fact, very different with reference to different kinds of effect, and to different modes of employment. With wires capable of transmitting the whole of the Electricity in proportion as it is supplied by the battery, the igniting power has generally been found to increase in exact proportion to the number of plates brought into action. This result was obtained by Mr. Wilkinson,* and by Mr. Cuthbertson,† and has been confirmed by the researches of Mr. Singer.‡ It corresponds also with the results of the experiments of Van Marum and Pfaff. From some experiments made with the battery of the Royal Institution, indeed, Sir Humphry Davy had at one time suspected that the increase of power proceeded according to the square of the number of plates, instead of being in the exact ratio of that number. When, on the other hand, a very considerable number of plates is employed, the igniting power no longer follows the same ratio; and even increases more slowly than the augmentation of the number of plates; and in some experiments it appears even to diminish. Thus Sir H. Davy found that one hundred plates ignited three inches of platina wire, one-seventieth of an inch in diameter; but one thousand similar plates, charged in the same way, ignited only thirteen inches.§ With a great number of plates it is, indeed, scarcely possible to obtain any satisfactory results; on account of so extensive a series being with difficulty equally charged in all its parts, and being also liable to various unavoidable sources of dissipation. All experiments of this nature require minute attention to a variety of circumstances which more or less affect the accuracy of the results.

And size of the plates.

(30.) When the same number of plates is employed, but their size is increased, the quantities of Electricity liberated are proportionally increased: but the power of ignition seems to increase in a much higher ratio with the increase of surface; probably higher than even the square. Thus twenty double plates each containing two square feet did not ignite one-sixteenth as much wire as twenty, each containing eight square feet, the acid employed being of the same strength in both cases.‖ The general fact, of which this experiment is a particular instance, appears to have been first noticed by the French chemists; and corresponds to a similar relation which is observed to take place between the effects of Leyden jars of different sizes in fusing metallic wires. The same proposition has also been established by Mr. Wilkinson, who states that the power of ignition, in batteries of the same total surface, but with plates of different sizes, increases in the proportion of the squares of the surfaces of the elementary plates, taken singly in each.¶ The forces of batteries having unequal surfaces were more carefully investigated, from the same data, by Mr. Harrison, of Kendal, in conjunction with Mr. Gough; and shown to be "in the ratio compounded of the number of plates, and the sixth power of the sides of the elementary plates, taken singly in each."** It follows that when the surfaces are equal, the igniting force is as the fourth power of the sides or diameters of the individual plates.[*]

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* Thomson's *Annals of Philosophy*, vi. 209.

* Nicholson's *Journal*, vii. 207.

† Ibid. viii. 97 and 205.

‡ Ibid. xxix. 32; and Singer's *Elements*, 412.

§ *Elements of Chemical Philosophy*, 156.

‖ Ibid.

¶ Nicholson's *Journal*, vii. 207.

** Ibid. ix. 241.

To the time during which the battery is applied.

(31.) Many are the circumstances which influence the continuance of the igniting power of the battery; but as they are connected with the condition of the plates and the agency of the fluid employed, they will come more properly under consideration in a subsequent part of our inquiries. It will be sufficient here to remark, that all Voltaic batteries require a certain time to produce their full effect; and that, accordingly, a sufficient interval must be allowed for the recovery of the powers of the instrument after each experiment, before a fresh contact is made between the communicating wires. A pair of plates, which on its first immersion in an acid solution, will intensely ignite a wire connecting the positive and negative surfaces, will cease to do so after the acid has acted on the plates for some moments; and ignition cannot be produced by the same apparatus, without a temporary removal from the fluid. Dr. Hare ascertained, that this recovery of the igniting power did not take place, if, during the removal from the acid, the galvanic surfaces be surrounded either by hydrogen gas, nitric oxide gas, or carbonic acid gas. When surrounded by chlorine, or by oxygen gas, the surfaces regain their igniting power in nearly the same time as when exposed to the air.[†]

6. *Requisite conditions in the communicating wire.*

And to the capacity,

(32.) Thus far we have considered the influence which different conditions of the Voltaic battery possess in regulating the quantity and power of the transmitted Electricity which produces ignition. We have next to notice various circumstances relating to the wire through which it is transmitted, which tend to modify this effect. The capacity of transmission in the wire will depend upon the nature of the metal, which, as we have already seen, has a greater or less conducting power with respect to Electricity, and also with respect to heat. These two properties appear to be nearly akin to one another; for the different metals follow nearly the same order with regard to their conducting powers both of Electricity and of heat. The radiating power of the metal is also to be taken into account. This power is known to depend on the extent of the surface, as well as on the particular quality of the surface. The ratio of the surface to the mass, is on this account an important datum for the estimation of the igniting effect produced by the transmission of the same quantity of Electricity through different wires. It is evident that the elevation of temperature produced by the passage of a given quantity of Electricity in a given time through a certain mass of conducting metal, of given capacity for heat, will be, *cæteris paribus*, inversely as the quantity of matter to be heated; and therefore, in wires of the same metal, inversely as the squares of the diameter. As far as this cause operates, therefore, the smaller the wire, the more intense will be its ignition, when other circumstances are the same. But, on the other hand, if we take into account the radiating power, we shall perceive that although the quantity of matter to be heated is thus lessened, yet the surface by which it is cooled does not diminish in the same ratio: the former, being, in equal lengths of wire, as the square; and the latter, in the simple ratio of the diameters. Within a certain limit, therefore, a thicker wire, which conveys more Electricity in proportion to its cooling surface, will be more heated than one more slender. Dr. Wollaston verified the truth of these conclusions by trials on the very minute wires which he employed in his elementary Galvanic battery already described: and he afterwards took the opportunity of confirming them on the largest scale, by means of the magnificent battery of Mr. Children, in the summer of 1813.[*]

Surface,

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(33.) However highly the conducting power of metallic substances for Electricity is to be estimated, it is evident that such power is not infinitely great; and that however small the obstacle which they interpose to the transmission of that power may be, still such obstacle exists in a certain degree; and the facility of transmission will be greater in proportion to the shortness of the distance the Electricity has to traverse. Hence the lengths of wire in the Voltaic circuit, which different batteries are capable of igniting to the same degree, may be taken as tolerably accurate measures of their respective powers of ignition. The same criterion will apply to the conducting powers. Thus Sir Humphry Davy found that when six inches of platina wire of a certain thickness discharged the Electricity of ten double plates; three inches discharged that of twenty; one and a half inch that of forty; and one inch that of sixty. The products of each of these pairs of numbers being equal in every case, it follows that the number of plates discharged by the wire is inversely as the length of that wire. By employing this method, a ready and accurate comparison can be instituted between the different metals with respect to their powers of conducting Voltaic Electricity. The contacts requisite for these comparative experiments may be made in a very short time; the batteries need not be changed, and their charge will suffer but little variation during the experiment. The results of Sir H. Davy's experiments conducted upon this plan, when reduced to equivalent whole numbers, expressive of the lengths of each metal required for discharging a Voltaic battery of sixty pairs of plates, are as follows:

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Silver	60
Copper	55
Gold	40
Lead	38
Platina	10
Palladium	9
Iron	8

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(34.) Another result connected with this subject, is that the conducting power is proportionate to the mass or thickness. The same mass, also, divided into a number of smaller wires, conducted equally well as when it only formed one wire of proportionate thickness. The extension of the surface of the wire by flattening through rollers, made no difference with regard to the conducting power, provided care was taken to preserve its temperature cool by surrounding it with water.[†] It is perhaps scarcely necessary to remark, that this result is perfectly consistent with water, with the expectation that they might be enabled to transmit a much higher charge of Electricity than they could convey in air without being destroyed. We have already seen that this conjecture was completely verified when put to the test of experiment.

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[*] Nicholson's *Journal*, ix. 243.

[†] *Annals of Philosophy*, viii. 317.

[*] Thomson's *Annals of Philosophy*, vi. 211.

[†] *Philosophical Transactions for* 1821, p. 433.

Of the intensity of the Electricity,

(39.) Hence, it appears, that the heat produced where Electricity of considerable intensity is passed through conductors, must always interfere with our obtaining an exact knowledge of the changes of their conducting powers. When, indeed, the intensity of the Electricity is very high, even the cooling powers of fluid media are of little avail. Thus it was found by Sir H. Davy, that a fine wire of platina was fused by the discharge of a common Electrical battery under water; so that the conducting power must always be diminished by the heat generated, in a greater proportion as the intensity of the Electricity is higher.

And power of the battery.

(40.) When the conducting medium is inadequate to the discharge of the whole of the Electricity in a battery, it might not appear probable that any increase of the power of the battery could enable the medium to carry through any additional quantity. Such, however, appears from the experiments of Sir H. Davy to be really the case. When saline solutions were placed in the circuit of a battery of twenty plates, though they discharged a very small quantity only of the Electricity, when the troughs were only one-quarter full, yet their chemical decomposition exhibited the fact of a much larger quantity passing through them, when the cells were filled with fluid. A similar circumstance occurred with regard to a wire of platina, of such a length as to leave a considerable residuum in a battery, when only half its surface was used; yet, when the whole surface was employed, it became much hotter, and nevertheless left a still more considerable residuum.

Differences in metals.

(41.) When equal portions of wires of the same diameter, but of different metals, were connected together in the circuit of a powerful Voltaic battery, acting as two surfaces, the metals were heated in the following order: iron most, then palladium, platina, tin, zinc, gold, lead, copper, and lastly silver, which was least of all. From one experiment, in which similar wires of platina and silver, joined in the same circuit, were placed in equal portions of oil, it appeared that the generation of heat was nearly inversely as their conducting power. Thus the silver raised the temperature of the oil only four degrees, whilst the platina raised it twenty-two. The same relations to heat seem to exist, whatever is the intensity of the Electricity; thus circuits of wires placed under water, and acted on by the common Electrical discharge, were heated in the same order as by the Voltaic battery, as was shown by their relative fusion; thus iron fused before platina, platina before gold, and so on.

Evolution of heat in the battery.

(42.) The evolution of heat by the circulation of Voltaic Electricity takes place, not only in that part of the circuit which connects the poles together; but is also distinctly manifested in the battery itself, every part of which, both the plates of metal and the fluid in the intervening cells, have their temperature raised. But, owing to the influence of a variety of circumstances, of which the effect cannot be accurately appreciated, this elevation of temperature is not equal throughout the whole series. From the trials made by Mr. John Murray, it would appear that a gradual increase of temperature took place in the successive cells from the negative to the positive pole. When a number of different troughs were joined together, the cells at their extremities were less heated than towards the middle region. The maximum of temperature in each was situated towards the positive pole, with a gradual declension in the direction of the negative pole.*

CHAPTER III.

Electro-Magnetic effects of Galvanism.

(43.) The influence which the transit of Electricity through conducting bodies exerts upon Magnetism, and the effects which result from this action, form one of the most remarkable and interesting subjects of modern science. As long as our knowledge of the operations of Electricity was confined to its more ordinary forms, there was little probability that the circumstances attending its connection with Magnetic phenomena would ever have been discovered. The science of Electro-Magnetism owes its birth to that of Galvanism. By supplying the means of putting into motion a vast quantity of Electricity, and of continuing its circulation for a considerable period, Galvanism has enabled us to detect its influence on the Magnetic needle, and to ascertain with precision the laws of its action.

(44.) Among the more remarkable of the physical effects of Galvanism, are now, therefore, to be ranked the induction of Magnetism in certain bodies, and the determination of a mechanical force, operating according to a certain law, in the bodies in which Magnetism has been thus induced, or which have previously acquired Magnetic properties. But these effects having been already fully considered in our Treatise on Electro-Magnetism, it would now be superfluous to detail or discuss them further. There is one point of view, however, relating especially to the present subject, in which it will be proper here to consider them, as it will assist us in the course of our inquiries. So many and so various are the links of connection, by which all the physical sciences are associated together; and so material is the aid which they mutually afford one another, that no one subject can be properly understood, or satisfactorily treated, without in some degree trenching upon the province of the neighbouring science. Thus, while to Galvanism we are indebted for the discovery of the Electro-Magnetic powers, these newly discovered properties have, in their turn, furnished us with further means of improving the parent science. The production of certain Magnetic phenomena, originally brought to light by the progress in Galvanic inquiry, have now themselves become the most delicate of all the known tests for ascertaining the operation of Voltaic Electricity, under circumstances where its quantity could not otherwise have been appreciated, nor even its presence detected. The phenomena of *Thermo-Electric-Magnetism*, as they have been called, and of which an ample account has already been given, are illustrations of this remark. The passage through wires of considerable quantities of Voltaic Electricity, when the circuit is complete, may be manifested by the ignition of the wires; but excepting the increase of temperature, no sensible ism.

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* *Edinburgh Philosophical Journal*, xiv. 57.

change is occasioned in the metal which transmits the Electricity. But its influence on magnetised, or magnetisable bodies, in its vicinity, will, by means of proper instruments, indicate the most minute quantities of circulating Electricity.

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(45.) The apparatus for examining these minute quantities of Galvanism, invented by Professor Cumming, and which he has termed a *Galvanometer* or *Galvanoscope*, has already been described in the Treatise on Electro-Magnetism, (p. 23,) as also another form of the same instrument, contrived by Mr. Marsh. The principle on which they operate is the equal action exercised on the Magnetic needle by all the parts of a conducting wire, when it transmits a current of Electricity. It is on this principle that the heliacal turns of wire in communication with the poles of a battery, conspire in producing Magnetic effects in the direction of the axis of the helix, that is, in a direction perpendicular to the plane of each of the coils. It is evident that this effect will be still further increased, the greater the number of coils which are made to act together upon the wire. Pursuing this idea, Professor Schweigger, of Halle, immediately after the discovery of Electro-Magnetism, invented an apparatus well adapted for detecting the feeblest Electrical currents; and it was afterwards somewhat improved in its form by Professor Oersted. The multiplying wire is of silvered copper, and its thickness about one-hundredth of an inch; for the purpose of guarding every part from any metallic contact, it is wrapped in its whole length in silk thread, which prevents all Electric communication between the different turns of the wire. In this form it may be denominated the Electro-Magnetic Multiplier. Dr. Kaerntz has laboured to prove experimentally the amount of the advantage obtained in these instruments by each additional circumvolution of the wire; and succeeded in verifying the deduction from theory, that the quantity of power of the instrument over the needle was exactly in proportion to the number of convolutions.*

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The Electricity developed by the contact of two discs, the one of copper and the other of zinc, when nothing but water is interposed between them, is perfectly appreciable by this instrument. It renders manifest Galvanic actions, which would be too feeble to excite contractions in the muscles of a prepared frog.

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(46.) It follows from the principles we have already explained and developed, concerning the transmission of Electricity through conducting wires, that in proportion as we lengthen the circuit which it has to traverse, by multiplying the number of coils, we interpose a greater obstacle to the transmission of the Electricity. It is necessary, therefore, to employ wires of a thickness proportioned to the charge which is to be measured. Thus, when the instrument is to be used for the comparison of considerable currents of Electricity, wires of much greater thickness must be employed; for without this precaution, there might be, instead of an increase, an absolute diminution of effect, in consequence of the imperfection of the conductor.

Part II.

(47.) In every instrument constructed upon the principles of the Galvanometer, or Electro-Magnetic Multiplier, the delicacy of its indications is much increased by placing one or more magnetised needles, in such a situation as shall greatly diminish, or completely neutralize the directive force which the suspended needle derives from the earth's Magnetism.

Nobili's Galvanometer.

A very happy application of this principle, calculated at the same time to increase the action of the wires on the needle, has lately been made by M. Nobili, in the construction of his new and highly ingenious galvanometer. The novelty of his contrivance consists in the employment of two Magnetic needles, instead of one. These needles are equal in size, and as nearly as possible brought to the same degree of Magnetism; they are placed the one above the other, fixed on an axis of straw, in parallel directions, but with their polarities directed in opposite ways, as represented in fig. 12. Their distance from each other on the straw is regulated by the construction of the frame with its covering wire, in and about which they are to move. This frame is twenty-two lines long, twelve wide, and six high. The wire is of copper, covered with silk; it is one-fifth of a line in thickness, and from twenty-nine to thirty feet long. It makes seventy-two revolutions about the frame. The needles are twenty-two lines long, three lines wide, a quarter of a line thick, and they are placed on the straw five lines apart from each other. An aperture is made in the tissue formed by the turns of the wire on the upper surface of the galvanometer, by opening them from the middle towards each side; the lower needle on the straw is introduced through this aperture into the interior; in consequence of which the upper needle remains a little above the upper surface of the wire. The aperture is retained open to a certain extent, to allow freedom of motion to the needles and straw; these being suspended in the usual way from the upper extremity of the straw. The graduated circle, on which the deviation is measured, is placed over the wire on the upper surface of the frame, having an aperture in its centre for the free passage of the needle and straw. The upper needle is the index, the lower being visible only from the sides of the instrument.

Fig. 12.

The superior sensibility of this instrument is owing to the addition of the upper needle. Being magnetised in an opposite direction to the lower one, it almost entirely neutralizes the influence of terrestrial Magnetism, leaving only so much of directive power as shall induce the whole arrangement to return to a constant position when uninfluenced by Electrical currents, and yet combining with the lower needle, to cause deflection when an Electrical current is passing through the wire.

As an illustration of the delicacy of this instrument, M. Nobili observes, that if Seebeck's combination of antimony and bismuth be attached to a common galvanometer, and the point of junction be cooled, only a very slight effect is observed on the instrument; whilst, if attached to the new galvanometer, the same influence is sufficient to make the needles revolve several times. If a piece of iron wire, five or six inches long, be used to connect the extremities of the copper wire of the instrument, by twisting the ends together, and one of the points of contact be warmed by touching it with the hand, the needle will move from zero, and in the first oscillation, extend to 90°. Even the mere approximation of the hand to the junction of the metals, will produce a deviation of 20°.

In consequence of the situation of the graduated circle above and on the outside of the frame, the folds of the wire may be brought much nearer to each other than in the common instrument; this renders it more compact, and from the vicinity of the needle within to the wire, also more powerful. When fixing the graduation, the zero should be placed so as to accord with the position of the needles, when left to the earth's influence; this will not be towards the true Magnetic north, but will not be far from it, and will always be constant.[*]

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* *Philosophical Magazine*, lxii. 441.

CHAPTER IV.

Chemical effects of Galvanism

Different circumstances of Galvanic action.

(48.) The effects of Galvanism to which our attention was first directed, and which might be regarded as more especially appertaining to Electricity in its ordinary forms, namely, attraction, repulsion, and induction, were obtained under circumstances in which the Galvanic circuit of the battery was incomplete, and were exhibited by the insulated and separate poles of the apparatus. The ignition of the communicating wires, on the other hand, or their elevation of temperature, and also their Electro-Magnetic effects, were the results of the free and uninterrupted transmission of Electricity through highly conducting substances, which formed the medium of connection between the positive and negative extremities of the battery. The class of phenomena which are next to be the subject of inquiry, depend, on the contrary, upon the influence of this astonishing agent on fluid conductors, which convey it only partially and imperfectly. They comprise certain chemical changes of composition, effected by the agency of Voltaic Electricity in the fluids which are interposed in the line of its circuit.

Chemical changes,

1. *Chemical changes occurring in simple Galvanic circles.*

In simple Galvanic circles.

(49.) In order to obtain clear ideas of the nature and connection of these effects, we shall first attend to what takes place in the simplest Galvanic circle, composed of two dissimilar metals and an interposed fluid; and as an example of most ordinary occurrence, we shall take the case which we originally assumed of a plate of copper, and another of zinc, occasionally communicating with one another at one end, either by direct contact or by means of an intervening wire; and immersed in an acid solution. Let us, in the first place, suppose this solution to consist of very dilute sulphuric acid. If the plates be immersed in this acid, without touching or communicating with each other, the acid will act upon the zinc; will first occasion the decomposition of the water in contact with it, the oxygen of which will combine with the zinc, forming an oxide of zinc; while the hydrogen will be disengaged in the form of gas. The oxide of zinc will then be dissolved by the acid, in proportion as it is produced. The plate of copper, on the other hand, will undergo no change; the acid, in its diluted state, having no power of acting upon it. Let the contact be now made between the metals, and the following consequences will ensue. The oxidation of the zinc, and its solution in the acid, will proceed with much greater rapidity and energy than before; but, what is still more remarkable, it will not be accompanied with the evolution of hydrogen from the oxidating surface. The proportion of hydrogen due to the oxygen which unites with the metal, will, indeed, be disengaged, but it will now make its first appearance on the surface of the copper plate, from whence it will arise in a copious stream of bubbles. The copper will itself be still unaffected by the new action that has been thus established. In process of time, indeed, when a considerable quantity of sulphate of zinc has been dissolved in the fluid, we find the quantity of disengaged hydrogen gradually diminish, and a film, composed partly of metallic zinc and partly of filaments of oxide of zinc, is deposited on the surface of the copper; as soon as this has been effected, the Galvanic action ceases.[*]

(50.) If an acid capable of acting upon the copper as well as upon the zinc, be employed in the experiment, similar phenomena take place, with this additional circumstance, that the action of the acid upon the copper ceases the instant the Galvanic circuit is completed; and instead of nitrous gas being formed on the surface of the copper, which happens before the circuit is formed, only bubbles of pure hydrogen make their appearance, and the copper is protected from all further action; the zinc being, as in the former case, oxidated and dissolved with additional energy.

2. *Changes effected in Fluid Conductors.*

(51.) The same chemical changes, which we have just described as occurring in a simple Galvanic arrangement, also take place in each of the portions of fluid, which intervene between the plates in each alternation of the series which constitute the composite batteries. As soon as the Galvanic circuit is completed, by establishing a sufficient communication between the poles of the battery, the zinc surfaces become rapidly oxidated, while the copper surfaces appear to give out hydrogen gas, and are protected from all chemical action.

Decomposition of Water.

(52.) Chemical actions of a still more remarkable kind take place, when fluid conductors are placed in any part of the circuit by which the two poles of the battery are brought into communication with one another. The first discovery of the chemical agency of Galvanism was in its power of decomposing water; it was one of the earliest fruits of the happy invention of the pile by Volta; and was due to the united researches of the late Mr. Nicholson, and of Mr., now Sir Anthony, Carlisle.

Let two metallic wires, each respectively communicating with the positive and negative poles of the battery be made to pass through the opposite ends of a glass tube filled with water, which may be confined by two corks, one placed at each end, allowing the wires to be introduced through them, so that their extremities may not be in contact, but may be at the distance of a quarter of an inch from each other,

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[*] *Bibliothèque Universelle*, xxix. 110; and *Journal of Science*, xx. 170.

[*] See Biot's *Memoir*, read to the National Institute, quoted by Wilkinson in his *Elements of Galvanism*, i. 163.

(fig. 10.) The following appearances will then present themselves. If the wire which is connected with the positive pole of the battery, be of a really oxidable metal, it is rapidly oxidated by the water when it is in contact with it; while at the same time, a stream of bubbles of hydrogen gas arises from the other wire which is so connected with the negative pole. It thus appears that the water has been decomposed into its two elements, of which the oxygen manifests its presence by entering into combination with the positive wire, and the hydrogen is developed in the form of gas at the negative wire.

(53.) If the wires employed be of a metal which is not susceptible of oxidation by water, such as gold or platina, gas will be extricated from both the wires, and by a proper apparatus may be collected separately. For this purpose we may take two glass tubes or receivers, closed at one end, and filled with water, which is retained by inverting them over a sufficient quantity of water in a glass vessel, as is shown in fig. 11. Each tube is to be furnished with a platina wire, N, P, passed through the closed extremity, and descending within it through its whole length. The open ends are then to be placed as near to each other as their position in the water will allow, and the wires to be connected respectively with the opposite surfaces of the Voltaic battery. Gas will immediately arise from each of the wires, but in different quantities. The tube containing the negative wire, N, will be soon filled with hydrogen gas, while the other, which is traversed by the positive wire, P, will, in the same time, be only half filled with oxygen gas. It is well known that the volumes of these two gases, which when in combination form water, or which result from its decomposition, are in this proportion, that is to say, the volume of the hydrogen is to that of the oxygen, as two to one. That the water is perfectly resolved into its two elements by this experiment is easily proved, by the test of mixing together the gases so procured, and exploding the mixture by an Electric spark; the whole instantly loses the gaseous form, and is reconverted into water.

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(54.) Sir H. Davy discovered that the gases constituting water may be separately produced from two quantities of water contained in separate vessels, provided they are made to communicate by moist conductors, such as moistened thread, extending from the one to the other. The same result will also be obtained if a slip of fresh animal substance, or a recent vegetable, be interposed between the two portions of fluid, or even if the fingers of the right hand be dipped into the water contained in one glass, and those of the left into the other. The most elegant mode of conducting this experiment is to use distilled water, and to connect the water in both cups by means of the fibres of amianthus or asbestos, previously moistened with pure water; by which means any saline or other impregnations, which the water may have previously contained, or may receive from the animal or vegetable substances employed as the medium of connection, are effectually guarded against.

Decomposition of Saline substances.

(55.) If the above mentioned precautions be neglected, the presence of saline substances will soon give rise to other phenomena, which although they are now sufficiently understood, were the source of great perplexity and error to the experimentalists who first noticed them. Thus it had been observed by Mr. Cruickshanks, among his earliest discoveries on the chemical effects of the Voltaic pile, that an acid and an alkali were generated at the two ends of the wire, when immersed in water, in the interrupted circuit. The same appearances were observed by Professor Pfaff, who ascribed them to the combinations of the azote, furnished by the atmospheric air which was contained in the water, with the oxygen on the one hand, and the hydrogen on the other, arising from the decomposition of the water, which thus produced nitric acid and ammonia.[*] Brugnatelli, and other inquirers, in like manner, obtained traces of acid and alkali by the Galvanic action of the wires on what they supposed to be pure water,[†] with only an admixture of a small quantity of common air. Desormes asserted that the acid was the muriatic; and the same conclusion was deduced by Simmer.[‡] This singular result led to the opinion, that muriatic acid on the one hand, and soda on the other, which had also been found under the same circumstances, were actually generated by some mysterious agency of Galvanism, out of the elements of pure water. A letter appeared in the *Philosophical Magazine*, in 1805, purporting to be written by a Mr. Peel, of Cambridge, and containing an account of an experiment, in which the water that remained after a large portion had been decomposed by Galvanism, yielded on evaporation a small quantity of muriate of soda. This salt, it was said, could not have been contained in the water employed for the decomposition, as every precaution was used to have it free from impurities. The experiment, it was pretended, had been repeated both by the writer and by a friend of his, with precisely the same result.[§] It appeared, however, on inquiry, that no such individual as Mr. Peel could be found at Cambridge, so that the letter bearing that name turned out to be a gross fabrication. But the most singular consequence of this attempt to impose upon the scientific world, was that when the experiment was tried by others, it was actually found to succeed; and accounts were received of the same results having in reality attended the experiments of Professor Pacchioni, of Pisa, as those mentioned in the fabricated letter. In order to account for the appearance of chlorine, or oxymuriatic acid, in water that had been subjected to the action of Galvanism, Pacchioni conceived that hydrogen might be susceptible of different degrees of oxidation; that muriatic acid was an oxide of hydrogen, being formed from water by the abstraction of part of its oxygen; while oxymuriatic acid consisted of hydrogen in a still higher degree of oxidation.[||] Mr. Sylvester, also, in this country, was led to the very same conclusion as to the appearance both of muriatic acid and of soda, in galvanised water, although he had used every endeavour to exclude muriate of soda from every part of the apparatus.[¶] These singular results, obtained at the same period by so many independent observers, could not fail to excite considerable attention, and gave rise

Perplexing appearances of acid and alkali to many bold speculations, as to the origin of the saltness of the ocean, which it was supposed might have been brought about by the mighty operations of the Galvanism of the globe. For the complete solution of these perplexing phenomena, science is indebted to the sagacity of Sir H. Davy. It is a remarkable feature in the history of this branch of Philosophy, that a random conjecture, hazarded originally, perhaps, as an idle jest, should have been afterwards apparently confirmed by repeated experiments in various quarters, and should have given occasion to the masterly train of investigations, which ultimately led to the discovery of the bases of the alkalies, and to the numerous splendid results with which modern science has been enriched, and which have immortalised the name of Davy.

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[*] Nicholson's *Journal*, xvii. 362.

[†] *Journal de Physique*, lxii. 298, and lxiv. 78.

[‡] *Annales de Chimie*, xxxvii. 284, and xli. 109.

[§] Vol. x. 221, 279.

[||] *Edinburgh Medical Journal*, i. 393.

[¶] Nicholson's *Journal*, xiv. 94, and xv. 50.

Explained by Sir H. Davy.

This illustrious philosopher soon ascertained that the muriatic acid which had been found owed its appearance to the animal or vegetable matters employed; for when the same fibres of cotton were made use of in successive experiments, and washed, after every process, in a weak solution of nitric acid, the water in the apparatus containing them, though acted upon for a great length of time with a very strong power, at last produced no effect upon solution of nitrate of silver. In the instances in which much soda had been procured, Sir H. Davy traced its production to the decomposition of the glass vessel at its point of contact with the wire, which he observed to be considerably corroded. By employing an agate cup, in place of the glass, this source of error was prevented, and no saline matter appeared. When the water in two separate cups were united together by well washed asbestos, as was happily suggested by Dr. Wollaston, neither acid nor alkali were at first produced by Galvanism. Yet in subsequent experiments they were found still to make their appearance. Vessels of pure gold were substituted for those of glass; acid and alkali were still developed, though in smaller quantities than before. By a series of careful experiments, in which approximations were successively made to the true result, it was found that even distilled water contained in ordinary cases sufficient saline matter to give rise to the observed phenomena. But when slowly distilled in a silver still, and decomposed in gold vessels, out of the contact of the air, no trace of either acid or alkali appeared; and it was finally established, after a very laborious investigation, that when the water is chemically pure, and that all access of foreign soluble matter is guarded against, the sole products resulting from its decomposition by Galvanism, are its two elements, oxygen and hydrogen.*

Law of the decomposition of saline bodies.

(56.) In the prosecution of these researches it was apparent, that the acid resulting from the decomposition of any neutral salt, which might be contained in the aqueous solution placed in the Voltaic circuit, was collected round the positively electrified metallic surface; and the alkaline matter round the negatively electrified surface. Thus was the power of the Voltaic battery as an instrument of chemical analysis made manifest; and the path of discovery which was thus laid open, was pursued with the greatest ardour and the most signal success. The apparatus employed consisted usually of two cups, sometimes of glass, but where more accuracy was required, of agate, or sometimes of gold; the cups were connected together by a few fibres of moistened asbestos, and respectively connected with the opposite poles of the battery. If a portion of any soluble saline compound was placed in each cup, and the action of the battery continued for a sufficient time, all the alkaline matter was found collected in the negative cup, and all the acid matter in the positive. If a solution of common Glauber's salt, or the sulphate of soda, be subjected to the action of the battery, after a few hours, the positive cup will be found to contain a solution of sulphuric acid, and the negative cup a solution of soda. Each of these elements must consequently have been transmitted in opposite directions through the moistened fibres, or rather through the water which they contain. Any other neutral saline compound will present similar phenomena.

(57.) The observation of the corrosion of glass by the Electrical agency, led Sir H. Davy to expect that various insoluble, or difficultly soluble bodies would undergo change under similar circumstances; and the result of these trials was decided and satisfactory. Two cups made of compact sulphate of lime, containing pure water, were connected together by fibrous sulphate of lime, which was moistened by pure water, and the Voltaic influence transmitted through it. After an hour the fluids were accurately examined; when it was found that a pure and saturated solution of lime had been produced in the cup containing the negative wire, which was partially covered with a crust of lime; and that the other cup was filled with a moderately strong solution of sulphuric acid. Sulphate of strontites, and fluate of lime, subjected to the same process, yielded similar results; but sulphate of barytes, from its greater insolubility, proved more difficult of decomposition; the difficulty was, however, at length overcome. The analysis of many mineralogical specimens of which the composition was considerably more complicated, was greatly elucidated by the action of Voltaic Electricity, which extracted all the acid and alkaline matters they contained. Basalt, for example, which contains 15 per cent. of lime, two and a half per cent. of soda, and only half per cent. of muriatic acid, gave, at the end of ten hours, evident traces of alkali round the negative, and of acid round the positive wire. Lime and soda were, in like manner, obtained from zeolite, and potash from lepidolite.

(58.) In whatever part of the fluid between the positive and negative wire the compound substance be placed, the ultimate results are still the same. Thus if the neutral salt, whether it be alkaline or earthy, be contained in one of the cups, and the other cup be filled with distilled water, the same transfer of either element takes place into the latter cup, according as it is connected with the one or the other of the wires; and at the end of the experiment the positive cup will contain the acid, and the negative cup, the alkaline or earthy base. This curious species of transfer may be beautifully illustrated by placing three cups, side by side, in a line, and connected together by moistened cotton. Let a solution of sulphate of potash, or of any other neutral salt be put into the middle cup, and blue infusion of cabbage into each of the others. When the communication is made with the Voltaic battery by immersing the wires into the fluid in the outer cups, the sulphuric or other acid will collect in the positive cup, and render its blue exhibited by a very moderate power. The former effects are best obtained by a battery brought rapidly into full action, by means of strong acid solutions acting upon the metallic plates; but the latter are accomplished with more certainty by the continuance of a more moderate and equal action of the battery for a considerable time, an object which is best attained by weaker acid solutions. Mr. Singer has given minute directions as to the best mode of adjusting the different parts of the apparatus for exhibiting the transfer of acid and alkali, by means of a power not exceeding thirty pairs of two inch plates. An infusion of the leaves of red cabbage may be made, by adding two or three drops of sulphuric acid to a pint of water, and infusing in it as many of the minced leaves as it will cover. After it has remained a day or two, the fine red liquor should be decanted and preserved in a closely stopped bottle. When wanted for the purpose of experiment, a portion is to be neutralized, by carefully adding a few drops of solution of ammonia, till it assumes a blue colour. Two watch glasses are to be filled with this blue fluid, and connected by a moistened fibre of cotton, or bibulous paper; they are then to be placed in the Voltaic circuit, by connecting one of them with the positive, and the other with the negative wire of the battery. In a short time, the fluid which surrounds the negative wire will assume a green colour, and that around the positive wire will be converted into a red, in consequence of the double transfer of alkali and acid. The decomposition of the whole of the salt will be completed in half an hour, the fluid in the negative cup becoming of a beautiful green, and that in the positive a bright red. If the situation of the wires be reversed, so that the cup which was positive may now become negative, and *vice versâ*, the colours will again change; the green will first become blue, and then red; and the red, after first returning to its original blue, will become green. This alternate transfer may be several times repeated with one charge.*

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* *Philosophical Transactions for* 1807.

Effects attending several interruptions of the circuit.

(66.) When different portions of fluid are placed in the same Voltaic circuit, which is formed by means of several pieces of wire, establishing the connection between the separate portions of fluid, the same changes take place in each, as happen when the communicating wire is interrupted by a single portion of fluid. Thus, if water be the subject of the experiment, oxygen is developed at all the points of the wire, out of which positive Electricity is flowing into each portion of water; and hydrogen is disengaged from the other extremity of the same wire, which is receiving the positive Electricity from the water. Thus every intermediate wire, between those in immediate connection with the battery, is collecting and giving out hydrogen at one extremity, and oxygen at the other. An arrangement of this kind is shown in fig. 13.

Fig. 13.

General fact thus established.

(67.) The general fact which has thus been established with regard to the chemical agency of Voltaic Electricity is, that there is one class of bodies, comprehending hydrogen, the alkaline and earthy bases, and all metallic substances, which when they exist in a fluid, and are in the line of action of the Voltaic circuit, are impelled from the positive towards the negative surface, through which that influence is conveyed; and that there is another class of bodies, consisting of oxygen, chlorine, and of the compounds in which these elements predominate, such as all acid bodies, which are impelled in the contrary direction, that is from the negative towards the positive pole. These bodies, after being thus distributed, are retained at their respective poles as long as the Electric currents are maintained; and, if it be consistent with their natural chemical affinities, frequently enter into combination with the metallic or other conducting surface through which the Electricity is transmitted to the fluid. Thus, if the surface which transmits positive Electricity be an oxidable metal, such as zinc, it becomes oxidated by the oxygen which is developed on that side from the decomposition of the water.

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The converse of this has already been exemplified, in the suspension of the chemical action of the nitric acid upon the copper plates in the cells of the battery, when the Electric circuit is completed. The same result will be obtained if a platina wire, proceeding from the positive pole of the battery, be introduced into a glass filled with diluted nitric acid. Let a copper wire be connected at one end with the negative pole, and the circuit completed by plunging its other extremity in the nitric acid. Under these circumstances the copper will not be acted upon by the acid; but the moment the Voltaic circuit is interrupted, it is dissolved rapidly.*

Decomposition of the Alkalies and Earths.

Influ Galv on C cal a ties.

(68.) The important facts which were thus clearly established, indicated a relation between the chemical affinities of bodies, and their natural states of Electricity; opened a wide field of speculation on the whole theory of Chemistry; and pointed out new paths of discovery in this department of physical science. Sir H. Davy pursuing the train of reasoning which they suggested, was led to the conclusion that chemical affinity is destroyed by giving to a body an Electricity opposite to that which naturally belongs to it; and that it is, on the contrary, increased by giving it a greater share of its natural Electricity. He thence inferred, that all those bodies which possess a strong chemical affinity for each other, such as acids and alkalies, are naturally in opposite states of Electricity. By inducing, therefore, upon any body an Electrical state contrary to the natural one, we may change all its chemical relations, and even succeed in resolving into their elements substances which would have resisted any other mode of decomposition. Guided by a theory so happily conceived, and armed with so powerful an instrument of analysis, the genius of Sir H. Davy triumphed over every obstacle, and led him on to the brilliant career of discovery, which has constituted so distinguished an epoch in the history of modern science.

Deco sition Potas

(69.) The two fixed alkalies had long been suspected of being compound bodies, but no reasonable conjecture had as yet been formed as to their real composition. After encountering some difficulties in contriving a proper apparatus, this great problem was at length resolved by the following experiment. A small piece of pure potash, which had been exposed for a few seconds to the atmosphere, so as to give, by its having imbibed a small quantity of moisture, conducting power to its surface, without perceptibly destroying its aggregation, was placed upon an insulated disc of platina, connected with the negative pole of the battery, of the power of 250 plates of six inches by four, in a state of intense activity; and a platina wire, communicating with the positive pole, was brought into contact with the upper surface of the alkali. The whole apparatus was in the open atmosphere. Under these circumstances, a vivid action was soon observed to take place. The potash began to fuse at both its points of electrization. There was a violent effervescence at the upper surface; at the lower, or negative surface, there was no liberation of Electric fluid; but small globules, having a high metallic lustre, and being precisely similar in visible characters to quicksilver, appeared; some of which burst with explosion and bright flame, as soon as they were formed; and others remained, and were merely tarnished, and finally covered by a white film, which formed on their surfaces. Numerous experiments proved that these globules were a peculiar inflammable principle, the basis of potash. The platina used in the experiment was in no way connected with the result, except as the medium for exhibiting the Electrical power of decomposition; and a substance of the same kind was produced when other metals, or even charcoal, were employed for completing the circuit. The production of this substance was independent of the presence of air, for it was obtained when the alkali was in the vacuum of an exhausted receiver. By a similar process a substance was procured from soda, which exhibited properties of an analogous nature, and which proved to be the basis of the mineral, as the former was that of the vegetable alkali. Both these substances, on being examined in a variety of ways, the detail of which would be foreign to our present purpose, were found to possess every property which can be deemed essential to characterise the metals; and it was concluded that the two alkalies are respectively the oxides of these new metals. The theory of the decomposition of the alkalies by Galvanism, is therefore sufficiently obvious, and is only a particular instance of the general facts above stated; namely, that combustible substances are developed at the negative, while oxygen is evolved at the positive wire. Subsequent experiments supplied all the proofs that were requisite in confirmation of these views. When solid potash or soda, in its moistened, or conducting state, was included in glass tubes, furnished with electrified platina wires, the new substances, (afterwards denominated *potassium* and *sodium*,) were generated at the negative surfaces; the gas given out at the other surface, proved, by the most delicate examination, to be pure oxygen; and unless an excess of water was present, no gas was evolved from the negative surface.

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* Nicholson's *Journal*, xxiv. 178.

* Singer, 360.

(70.) The new metallic substances were reconverted into potash and soda, by simple exposure to the air, with the oxygenous part of which they were found to have combined. If oxygen gas alone was in contact with them, the combination was immediate; the globules becoming covered with an alkaline crust. When the combination is more rapid, as happens when they come in contact with water, the phenomenon of the reproduction of the alkalies is attended with the sudden extrication of light and heat. Thus were the results of analysis confirmed by those of synthesis.

Decomposition of the earths.

We forbear to detail the elaborate series of experiments which were made in order to ascertain the physical properties of these new metals, and their chemical relations with other bodies, because they relate more properly to the science of Chemistry than of Galvanism; nor does it come within our province to notice the discussions which ensued respecting the nature of potassium and sodium, and the hypothesis that they were compounds of other metallic bases and hydrogen; an hypothesis which was afterwards abandoned. Any notice of the experiments which appear to indicate the metallization of ammonia, must in like manner be omitted in this place. We can only slightly advert to the decomposition of the earths, as being among the more direct results of Galvanic decomposition. These bodies, which, having so many properties in common with the alkalies, might be supposed from analogy to be similar in their composition, were found much more difficult to decompose, and many ineffectual attempts were made to effect their analysis. But the difficulty was, at length, in some measure overcome by mixing the earth with a metallic oxide, and placing the mixture in contact with a globule of mercury communicating with the negative pole of the battery. In this way an amalgam was formed, consisting of the mercury and the metal of the earth employed. A metallic basis appeared to have been obtained from the four earths which are most capable of forming neutral salts with acids, namely lime, barytes, strontites, and magnesia. To these metals the names of *calcium*, *barium*, *strontium*, and *magnium*, were respectively applied. The remaining earths, namely, silex, alumina, zircon, and glucine, were still more refractory; in consequence, probably, of the more powerful affinity of their bases for oxygen. Their decomposition could not be effected by the same means which had succeeded with the alkaline earths; but it was at length partially accomplished by keeping the earth in fusion in potash, inducing upon it positive Electricity, and touching it with a negative wire. An amalgam was thus produced, which probably consisted of the metallic base of the earth employed and potassium. Although by these processes some of the properties of the metallic bases of the earths have been brought to light, these substances have never been obtained in sufficient quantity to admit of any accurate examination.

Other instances of decomposition.

(71.) The applications of the Voltaic battery to the purposes of chemical decomposition are various and extensive. Thus sulphuric acid is resolved by its means into oxygen gas, at the positive wire, and sulphur, which is deposited at the negative wire. Phosphoric acid, in like manner, yields oxygen gas and phosphorus. Ammonia separates into hydrogen and azote, with a small proportion of oxygen. Oils, alcohol, and ether, when acted on by a powerful battery, deposit charcoal, and give off hydrogen, or carburetted hydrogen. Mr. Brande has shown that when animal fluids containing albumen are placed in the Voltaic circuit, the albumen is separated in combination with alkali at the negative wire, and in combination with acid at the positive wire. With a powerful battery, it separates at the negative wire in the solid form; and with a less power, in the fluid form: a fact which gives countenance to the hypothesis, that an Electric power is concerned in the animal process of secretion.*

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* *Philosophical Transactions for* 1809, p. 385.

society of Dutch chemists. Messrs. Dieman and Van Troostwyk employed for this purpose a glass tube one-eighth of an inch in diameter, and twelve inches long, through one end of which a gold wire was inserted, projecting about an inch and a half within the tube; that end being then hermetically sealed. At the distance of five-eighths of an inch from the extremity of the first wire, another wire was fixed, extending to the open end of the tube. The tube was next filled with distilled water, and inverted in a vessel also containing water. Electrical shocks were then passed between the two ends of the wires through the water; and when these shocks were sufficiently strong, bubbles of air were formed at each explosion, and rose to the top of the tube. As soon as a sufficient quantity had collected to leave the upper end of the wire uncovered by the water, the next shock that was passed set fire to the mixed gases, and the water rose again in the tube, and entirely filled it, as at the outset of the experiment.

(77.) The principal difference in the effect thus produced by common Electricity and in that obtained by Galvanism, is that, in the former case, the two gases are obtained promiscuously from both ends of the wire, and not, as in the latter case, the oxygen from one end, and the hydrogen from the other. The decomposition of water is effected with incomparably greater facility by Voltaic Electricity, since an apparatus of very moderate power is sufficient for the purpose; while it has been generally thought necessary to use powerful Electrical machines, and large Leyden jars for accomplishing this object. Dr. Wollaston, however, succeeded in producing a very close imitation of the Galvanic phenomena of decomposition by ordinary Electricity. Perceiving, with his accustomed sagacity and penetration, that the decomposition would depend on duly proportioning the strength of the charge of Electricity to the quantity of water; and that the quantity exposed to its action at the surface of communication depends on the extent of that surface, he conceived that by reducing the surface of communication, the decomposition of water might be effected by smaller machines, and with less powerful excitation, than had hitherto been used for the purpose. Having procured a small wire of fine gold, and given to it as fine a point as possible, he inserted it into a capillary glass tube; and after heating the tube, so as to make it adhere to the point, and cover it in every part, he gradually ground it down, till, with a pocket lens, he could discern that the point of the gold was exposed. When sparks from a prime conductor of an Electrical machine were made to pass through water, by means of a point so guarded, a spark, passing to the distance of one-eighth of an inch, would decompose water, when the point exposed did not exceed 1-700th of an inch in diameter. With another point, estimated at 1-1500th, a succession of sparks, one-twentieth of an inch in length, afforded a current of small bubbles of air. With a still finer filament of gold, the mere current of Electricity, without any discernible sparks, evolved gas from water. The appearance of two currents of air may also be imitated, by occasioning the Electricity to pass by fine points of communication on both sides of the water; but, in fact, observes Dr. Wollaston, the resemblance is not complete; for in every way in which he tried it, he observed that each wire gave both oxygen and hydrogen gas, instead of their being formed separately, as by the Voltaic apparatus.

Decomposition of Salts.

(78.) When a solution of sulphate of copper was subjected to the action of common Electricity by means of these slender conducting wires, the metal was revived round the negative wire. Upon reversing the direction of the current of Electricity, the copper was soon redissolved, and a similar precipitate was formed on the opposite wire, which was now rendered negative. Analogous experiments made with other metallic solutions presented similar results. The oxidating power of positive Electricity was also proved by its effect on vegetable blue colours. A current of Electric sparks was transmitted along the surface of a moistened card, coloured with a strong infusion of litmus, by means of two fine gold points touching the card at the distance of an inch from each other. The effect, as in other cases, depending on the smallness of the quantity of water, was most discernible when the card was nearly dry. In this state, a very few turns of the machine were sufficient to occasion a redness at the positive wire, very manifest to the naked eye. The negative wire being afterwards placed on the same spot, soon restored it to its original blue colour.* By employing an apparatus similar to that of Dr. Wollaston, Sir H. Davy has effected the decomposition of sulphate of potash by common Electricity; potash appearing at the negative, and sulphuric acid at the positive pole.†

Inference as to the identity of the agents.

(79.) The important series of experiments, of which we have now given the results, have removed all doubt of the identity of the Electricity evolved by Galvanism, with that excited by the ordinary Electrical machine.

CHAPTER V.

Physiological Effects.

Galvanism acts upon the nervous system.

(80.) The effects of Galvanism on the animal body, are all ultimately referable to its action on the nervous system. The most obvious and immediate of these effects are the production of certain sensations, and the excitation of muscular contractions; the more remote and indirect effects are seen in its influence on the function of secretion.

1. *Action of Galvanism on the external Senses.*

Perception of the shock.

(81.) If any considerable portion of the human body be placed in the circuit of a Voltaic pile or battery, a distinct shock will be felt every time that the connection of conductors is made. For the production of this effect, however, it is requisite that the cuticle, through which the influence is to be transmitted, be sufficiently moistened; for in its usual dry state, it acts as a non-conductor to Electricity of such feeble intensity as that which is presented by the poles of the Voltaic battery. The most effectual mode of receiving the whole force of the battery is to moisten both hands with water, or, what answers still better, with brine, and grasping a silver spoon in each, to touch one extremity of the battery with one spoon, and the opposite extremity with the other. Another mode is to immerse the extremities of the two conducting wires into two separate vessels filled with water, into which a finger of each hand should be plunged.

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* *Philosophical Transactions for* 1801, p. 427.

† Ibid. for 1806.

Circumstances attending it.

Pain in the denuded nerve.

Effects on the blood-vessels.

(82.) The shock received from the Voltaic pile resembles very nearly the sensation produced by a weak charge from a very large Electrical battery. It is more intense in proportion to the number of alternations of plates composing the pile. Twenty pair of plates are sufficient to give a shock, which, when fully received, is felt in the arms. With a hundred pair it is felt in the shoulders. The current of Electricity, which continues to flow through the body as long as it makes part of the circuit, generally manifests itself by the continuance of a painful sensation. If it be received by a part of the body from which the cuticle has been removed, a severe smarting sensation is experienced, which, if the denuded surface be large, increases till it becomes almost insupportable. The smallest cut, burn, or excoriation, near the part in communication with the pile, will give rise to this painful feeling. When the cuticle is entire, it requires the accumulated power of a number of plates to produce any sensible effect; but in more sensible parts, where the nerves are exposed to their action, a single pair of plates, forming a Galvanic combination, is sufficient to excite acute sensation. Professor Robison tried the experiment with the surface of a cut which he had accidentally received, and to which he applied one of the metallic substances, completing the circuit with other parts of the surface of the body with which the other metal was in contact; and afterwards effecting a communication between the two metals by means of a wire; an acute pain was immediately felt in the wound. He also succeeded in bringing on the tooth ache by applying one of the metals to the nerve of a carious tooth. Humboldt, who prosecuted experiments on Galvanism with an ardour and perseverance which have rarely been equalled, informs us, that with a view of ascertaining more precisely the nature of these effects, he purposely applied two blisters over the deltoid muscles of his arms. He covered one of the wounds with a large silver medal, and the other with a plate of zinc, and by means of a zinc wire established a communication between the two metals. The result of the contact was not only a violent smarting sensation on the blistered surfaces, but an alternate contraction of the muscles of the shoulder and of the neck. When the blistered surfaces had been exposed to the air for the space of half an hour, so as to have become covered with effused lymph, the effect of the Galvanic contact was much diminished. But when, under these circumstances, a few drops of an alkaline solution were poured on the coating of lymph, the sensibility was immediately restored, and the pain became extremely violent; and the contractions were renewed, and succeeded each other several times successively. Not satisfied with these results, he wished to obtain proofs of the further action of Galvanism on the actions of the blood-vessels. Having abraded the skin of the wrist, attended with the effusion of a small quantity of blood, at the part where the radial artery is extremely superficial, he laid on the wound a coating of zinc, which he touched with a silver coin. As long as the contact continued, he felt a tension which extended to the end of his fingers, together with a shooting and tremulous sensation in the whole extent of the palm of the hand. This painful sensation became manifestly more intense, whenever the edge of the coin was brought in contact with the zinc; and the irritation likewise augmented the discharge of blood. The coagulation of the blood, however, intercepted the action, and diminished the effect. Humboldt now took a scalpel, and, having made a slight incision in the part, the Galvanic process, which he continued for several days successively, produced a very decided inflammation.[*]

(83.) On another occasion, the same intrepid experimentalist subjected the skin over the trapezius and deltoid muscles to a trial similar to the preceding; and ascertained that the continued application of Galvanism, renewed the serous discharge from the vessels of the skin, accompanied by a change of colour, a very acute pain, redness, and inflammation. On repeating this experiment, he remarked that the sensation which Galvanism excited in him, did not appear to have the slightest resemblance with that which is occasioned by Electricity. It appearead to him to be a pain of a very particular and distinct nature. It is to be observed, however, that Humboldt had adopted the opinion, that the agents which produced Electric and Galvanic effects were distinct from one another.

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(84.) Volta has remarked, that the action of the pile on the parts where the true skin has been laid bare, was productive of a sharper kind of pain on the negative side of the apparatus, that is, where the positive Electricity flowed out from the wound, than where it entered. This fact had previously been noticed with regard to the pungency of the common Electric spark.[†]

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(85.) If any part of the face near the eyes be included in the circuit of the battery, a vivid flash of light is perceived at the moment of contact by the person on whom the experiment is made. This sensation is felt whether the eyes be open or closed, or whether it be made in day light or in the dark; it depends evidently on an impression produced on the retina, or optic nerve, similar to that which is excited by the admission of light to the eyes. It is a phenomenon analogous to the effect of a blow on the eye, which excites the sensation of a bright luminous coruscation, although no light be really present. If the pupil of the eye be attentively watched in this experiment, it will be seen to contract as often as the metals are brought into contact. The flash of light produced by a pile which contained 111 plates of silver was so powerful, that the physiologist who made the experiment was not disposed to repeat it.[‡] But the simplest Galvanic combination, if applied to the tongue and lips, is sufficient to occasion the perception of a flash; while at the same time a strong metallic taste is perceived on the tongue, where it is in contact with one of the metals. The most effectual mode of obtaining the flash, is to place one metal between the upper lip and the gums; or to insert a wire of one metal into the nostrils, while a plate of the other metal is laid upon the tongue, and then effecting the contact between them. It is also produced by covering the bulb of the eye with tinfoil, placing a silver spoon in the mouth, and then completing a metallic communication between the tinfoil and the spoon; or the tinfoil may be placed upon the tongue, while the rounded end of a silver probe is applied to the internal angle of the eye.

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[*] Wilkinson, *Elements*, i. 161, 284, and 296.

[†] Nicholson's *Journal*, 4to, iv. 180.

[‡] Wilkinson, *Elements*, ii. 6.

The peculiar taste above alluded to, is perceived on placing one of the metals on the upper, and the other on the under surface of the tongue, whenever these metals are brought into contact. This fact was the first phenomenon strictly appertaining to Galvanism, that had been noticed: it was originally mentioned by Sulzer, a German metaphysical writer, in a work published in 1767, entitled *The General Theory of Pleasures.* The experiment was varied by Humboldt in the following manner. By applying a flattened piece of zinc to one of the surfaces of the tongue, and a flattened piece of silver to the other surface, without either of their coatings touching the other, but each of them provided with a long iron wire; and by passing the wires, in a parallel direction through a door, behind which they may be brought together, and separated alternately; the person who makes the experiment may ascertain, by the taste he feels on his tongue, whether the extremities of the wires are in contact. The presence of saliva is essentially connected with the production of this phenomenon. Fabroni remarked, that when he wiped his tongue with all possible care, the sensation resulting from the contact of the metals was diminished to such a degree as to be scarcely distinguishable.

(86.) A difference has been remarked in the taste perceived by the tongue, according to the metal which is laid upon it; zinc giving rise to an acid, and silver to an austere, or alkaline taste. It is augmented when one of the metals has been rubbed over with mercury, which renders the contact more perfect. When the power of several plates is combined, all these effects are augmented, and attended with an abundant discharge of saliva. Professor Robison remarked, that the drinking porter out of a pewter pot produces a more brisk sensation than when it is taken out of a glass vessel; which he ascribes to a Galvanic effect. In this instance there is a combination of one metal and two dissimilar fluids, which, as we shall afterwards find, constitutes a Galvanic circle. In the act of drinking one side of the pewter pot is exposed to the action of the saliva which moistens the lip, while the other metallic side is in contact with the porter; the circuit being thus completed, an agreeable relish is communicated to the latter when it comes in contact with the tongue.

(87.) The following experiment of Volta is another illustration of the same general fact. He took a basin of zinc, placed it on a silver stand, and filled it with water. When a person applied the tip of his tongue to the water, he found it perfectly tasteless as long as he did not touch the silver stand; but whenever he laid hold of the stand with the hand previously moistened, he experienced on the tongue a strong acid taste. This experiment will succeed, although the effect be weaker, with a chain of several persons who hold each other's hands, after they have been moistened with water; while the first person applies the tip of his tongue to the water in the basin, and the last lays hold of the silver stand.*

(88.) With a view of increasing the effect resulting from a single pair of plates of different metals, Professor Robison arranged a series of zinc and silver plates, about a quarter of the size of a shilling so as to form a rouleau; and on applying his tongue to the edge of the rouleau, the sensation experienced was more manifest than when a single pair was employed: but, for reasons that will appear hereafter, its power was not in other respects more considerable. The same philosopher also states, that he could ascertain from the peculiar impression made upon the tongue on the application of gold or silver trinkets, whether any solder was employed in making them.

(89.) It may here be observed, that common Electricity received by the tongue excites sensations very analogous to those which result from Galvanism. Berzelius remarks that positive and negative Electricity may be readily distinguished by the taste, on making the Electric current pass by means of a point to the tongue. The taste of positive Electricity is acid; that of negative Electricity is more caustic, and, as it were, alkaline.

Effects of Galvanism on the senses of smell and hearing.

(90.) Cavallo conceived that he had proved, by the following experiment, the influence of Galvanism on the olfactory nerves. Having brought together a silver thread, forced as high up as possible into the nostril, and a piece of zinc, laid on the tongue, he was sensible of a putrid smell, more especially after having forcibly pulled the silver in the nostril. This experiment has however been frequently repeated by Reinhold, Fowler, and others, without any such result having been obtained. Attempts have likewise been made to excite the auditory nerves by Galvanism so as to give rise to perceptions of sound; but hitherto without the least success: unless we consider as such the experiment described by Volta, who after having introduced into each ear a blunt metallic probe, and directed through the head, by their means, a current of Voltaic Electricity, was sensible of a peculiar sound, similar to that of ebullition or decrepitation. He did not think it safe, however, to repeat this experiment.

2. *Excitation of Muscular Contractions by Galvanism.*

Muscular contractions,

(91.) The physiological effects of Galvanism which almost exclusively occupied the attention of philosophers, previous to the discovery of the pile, were those in which contractions in the muscular parts of animals were exhibited. It was the observation of a fact of this kind by Galvani which gave rise to the first inquiries on the subject, and which may be said to have laid the foundations of the science which now bears his name. The source of that surprising power which called forth such sudden and forcible muscular contractions, as took place when the nerve and muscles of the limb of a frog were respectively in contact with different metals, which were themselves made to communicate, either directly or by the intermedium of other metals, was most anxiously sought for: and it was not till after a long period of laborious research, in which a prodigious number of experimentalists in every part of Europe engaged, and occcasionally involved themselves in inextricable mazes of perplexity, that the identity of the Galvanic and the Electric agencies was recognised and finally established. An opinion had been very prevalent, that the real source of the power developed existed in the muscle and nerve which formed part of the circuit;

Ascribed to animal Electricity.

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* Wilkinson, *Elements*, i. 121

and that the metals which composed the other part, acted merely as the conductors by which that agency was transferred from the one to the other of these animal structures. The discoveries of Volta, relative to the Electrical agencies of the pile, dispelled this error, by proving that the source of power resided in the Galvanic arrangement of the metals themselves, when combined with certain fluids: and placed beyond the reach of controversy the fundamental principle that this power was Electricity. From this period the excitation of muscular contractions was regarded merely as one of the effects of the passage of Electricity through the animal organs, and ceased to attract attention as manifesting the operation of some hidden energy peculiar to the nervous and muscular systems of animal life.

General facts respecting them.

(92.) Viewed in this light, then, the innumerable phenomena, which have presented themselves in the course of the inquiry, relative to animal Galvanism, may all be reduced to the following general fact: namely, that when a certain portion of a nerve, which is distributed to any muscle, is made part of a Galvanic circuit, contractions, generally of a violent and convulsive kind, are produced in that muscle. The varieties of form of which the experiment, which has thus been stated in general terms, is susceptible are endless; and will readily present themselves to those who are in possession of the principles which we have already explained with regard to the conditions on which Galvanic effects are dependent. We shall therefore content ourselves with pointing out a few of the clearest and most striking instances.

Experiments in illustration.

(93.) The limbs of a frog, being peculiarly susceptible to the influence of Galvanism, have been generally chosen as the fittest for such experiments. In order to prepare them for this purpose, it will be found most convenient to separate the head and upper extremities from the rest of the body, and to remove the contents of the abdomen, and also the skin of the lower extremity. The great bundle of nerves, which forms what is called the sciatic nerve, and is distributed to the muscles of the thigh and leg, may then be distinctly seen on each side. The spine may then be separated below the origin of these nerves, so that it may remain attached to the legs by the nerves only. All the superfluous part of the spine is to be cut off, and the small piece that remains attached to the nerves, together with the nerves themselves, are to be wrapped round with tin-foil. If the legs be now placed on a piece of silver, and the two metals be brought into contact, or be made to communicate with one another by a wire of metal, violent contractions will immediately be excited in all the muscles of the limbs; and these motions will be renewed as often as the contact is made between the conducting wire and the two metals, and as long as the muscle retains its irritability.

(94.) Similar effects are produced if the different metals are in contact in any part of the circuit, and a communication be made by fluid conductors with the nerve and muscle. It has been ascertained by Dr. Fowler, that provided the Galvanic influence passes through a portion of the nerve, it is not necessary that the muscle be comprehended in the circuit of this influence; for the moisture which covers the surface, and pervades the substance of the muscle is sufficient to perform the office of a conductor. Humboldt found that the Galvanic influence was communicable through a series of several persons who joined their hands, previously moistened, in order to render the cuticle sufficiently conducting. Having, in the course of his laborious researches, composed a chain of seven or eight persons, he occasionally remarked that the movements of the muscles did not take place, until one person, who constituted part of the chain, had quitted it. He was frequently at a loss to discover the non-conducting individual, until all the persons who composed the chain had withdrawn from it in succession. It was in vain that this individual wetted his hands; nothing could give them that conducting property which nature seemed to have refused to him.

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(95.) The same process applied to other animals, and even to the human body, will succeed in producing similar effects. In the hospital of St. Ursula, at Bologna, similar trials on the amputated legs and arms of patients were made with perfect success. These experiments have been repeated by a great many physiologists, and varied in a great number of ways, with similar results. When large animals are made the subject of experiment, and the power of the Voltaic pile or battery is employed, the effects are exceedingly striking, and sometimes terrific in the eyes of the spectator, who can scarcely persuade himself but that the convulsive movements he beholds are indications of returning life, and of the most acute suffering. If two wires be placed in the ears of an ox, sheep, or other animal soon after its death, and one of the wires be connected with one pole of a battery of a hundred plates; whilst the other wire is brought occasionally in contact with the opposite pole, at every completion of the circuit very strong muscular actions will be excited; the eyes will be seen to open spontaneously, and roll in the sockets as if endued with the power of vision; the pupils at the same time becoming dilated: the nostrils will vibrate in imitation of the act of smelling; and the jaws will immediately begin their usual actions of mastication. These convulsive actions, when the head is still warm, and has not long been separated from the body of the animal, are very considerable. The ears move with great activity and force; and when the tongue has been previously drawn out, and secured to the table by an iron skewer, which is made to penetrate more than half an inch into the wood, it is retracted with such force on the application of Galvanism, as to detach the skewer from the table, and to throw it up into the air to a considerable height. An entire sheep subjected to the action of the battery exhibited motions resembling the convulsive struggles of animals in an epileptic state, and much more powerful than the natural actions. Two horses, recently killed, which Mr. Wilkinson galvanised, required two persons to restrain the motions of each of the legs.*

Expe ment the h body

(96.) Similar experiments have often been made both in this country and on the continent, and on the bodies of criminals soon after their execution. Vassali-Eandi, in conjunction with his friends Giulio, and Rossi, made a great number on several victims to the guillotine at Turin.† Aldini, by operating with a considerable series of plates, on the body of a criminal executed at Newgate, produced violent agitations of the limbs: the eyes opened and shut; the mouth and jaws worked vehemently; and the whole countenance was thrown into hideous convulsions. Dr. Ure performed similar experiments at Glasgow, on the body of a murderer which was given up to him for dissection. A pointed rod connected with one end of the battery was introduced into an incision made in the nape of the neck, so as to be in contact with the spinal marrow, while another rod was applied to the sciatic nerve. On applying the power of a battery of 270 pairs of four inch plates, every muscle of the body was agitated with convulsive movements, resembling a violent shuddering from cold. On moving the second rod from the hip to the heel, where an incision had also been made, the knee being previously bent, the leg was thrown out with such violence, as nearly to overturn one of the assistants, who in vain endeavoured to prevent its extension. The muscles of respiration were called into action by directing the influence of Galvanism through the phrenic nerve, so that the chest heaved and fell, as in natural breathing. The supra-orbital nerve was laid bare in the forehead, and one conducting rod being applied to it, and the other to the heel, most extraordinary grimaces were exhibited every time the Electric discharges were made: "every muscle in the countenance was simultaneously thrown into fearful action; rage, horror, despair, anguish, and ghastly smiles, united their hideous expression in the murderer's face, surpassing far the wildest representations of a Fuseli or a Kean. At this period several of the spectators were forced to leave the apartment from terror or sickness, and one gentleman fainted." The last experiment consisted in transmitting the Electric power from the spinal marrow to the ulnar nerve at the elbow; "the fingers now moved nimbly, like those of a violin performer. An assistant, who tried to close the fist, found the hand open forcibly in spite of his efforts. When one rod was applied to a slight incision in the top of the fore-finger, the fist being previously clenched, that finger extended instantly; and from the convulsive agitation of the arm, he seemed to point to the different spectators, some of whom thought he had come to life."*

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* Wilkinson, *Elements*, ii. 464.

† *Journal de Physique*, lv. 286.

(97.) Every species of animal appears to be susceptible of the Galvanic influence. The nervous organization of fishes particularly adapts them to these experiments. Humboldt has made a great number on this class of animals. "I have seen," he observes, "fishes, the heads of which had been cut off half an hour before, strike with their Galvanised tail in so forcible a manner, that the whole of the body was raised considerably above the table on which they were placed." When the excitation was increased by alkaline solutions, or by chlorine, the struggles of the fishes, more particularly of eels and tench, were such that it was scarcely possible to master them. The slightest contact of metallic substances made them spring to a considerable distance. If a live flounder be placed in a dish upon a slip of zinc, and a shilling be placed on its back; whenever the zinc and shilling are brought into metallic communication by means of a wire, strong muscular actions are excited.

(98.) Some of the animals belonging to the class of *Vermes* exhibit their sensibility to Galvanism in a very decided manner. Let a crown piece be placed upon a plate of zinc of larger size, and a leech be put upon the silver coin; as long as it remains in contact with the silver only it will betray no uneasiness: but no sooner does it stretch out its head so as to touch the zinc, than it immediately recoils as if it experienced a painful shock. The same happens if an earth worm be made the subject of a similar experiment. The *nais*, which is an aquatic worm, also exhibits these effects in a very striking manner. Humboldt likewise found that the *lernæa*, or water serpent, and even the *tænia*, *ascaris*, and other species of intestinal worms, had their movements evidently accelerated by the influence of Galvanism. This was, however, at the expense of their life.

On the Amphibia.

(99.) The physiological condition of the *amphibia* renders this class of animals peculiarly fitted for the exhibition of the effects of Galvanism, both on account of the great susceptibility to its influence which is inherent in their nervous system, and on account of the extraordinary tenacity of the powers of life which characterises them. The muscular and nervous organization of a frog has accordingly been considered as the most delicate electroscope in nature. It is incomparably more sensible to the Electricity developed by the contact of two dissimilar metals than the gold-leaf electrometer of Bennet. But, on the other hand, it is much inferior to the Electro-Magnetic multiplier, of which we have already given a description.

Influence of Galvanism on the involuntary Muscles;

(100.) Volta had asserted that the heart, and other muscles whose action is not under the guidance of the will, were incapable of being affected by Galvanism: but Fowler has sufficiently shown that they might be acted upon, if the experiment be properly conducted: and his results were confirmed by Vassali, who proved that not only the heart, but the muscular fibres of the stomach and intestines might also be excited by Galvanism. Humboldt succeeded in producing contractions in the hearts of frogs, lizards, and toads; and also in those of fishes. Similar results were obtained by Nysten, who published an elaborate Treatise on the subject.* Bichat was of opinion that the nerves connected with the great sympathetic, and with the ganglia belonging to those which are distributed to the organs of what he calls the organic functions, are much less susceptible to the action of Galvanism, than the nerves which supply the voluntary muscles.† Circaud conceived he had discovered that the fibrin of the blood, immediately after it has been taken from the vessels, could be made to contract by the Galvanic apparatus. De la Metherie confirmed the statement of Circaud; but the experiment has not succeeded in this country, even when conducted in the most careful manner When we consider the difficulty and delicacy of the process, we may be allowed, indeed, as Dr. Bostock observes, without impeaching the veracity of the narrators, to entertain some doubts on the subject.‡

On the Fibrin of the Blood.

3. *Influence of Galvanism on arterial action and secretion.*

On Arterial action.

(101.) The influence of Galvanism on the actions of the arteries, both in augmenting the force of their

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* *Journal of Science*, vi. 283.

* *Nouvelles Expériences Galvaniques*, 1803. See also *Journal de Physique*, lv. 465.

† *Sur la Vie et la Mort*, 336.

‡ *Journal de Physique*, lv. 402.

On the Gastric secretion.

contractions, in inducing hemorrhagic and inflammatory actions, and in increasing and affecting the nature of the secretions, has been proved by a great number of facts. The most remarkable of these latter effects are those which have been lately established by the researches of Dr. Philip; who found that the secretion of the gastric juice in the stomach, which had been suspended by the division of the eighth pair of nerves, was restored on establishing the Voltaic current of Electricity through the divided portion of the nerves next to the stomach. The accuracy of the experiments on which this conclusion is founded, was for a long time disputed; but it has lately been satisfactorily established, by their careful repetition at the Royal Institution by Dr. Philip, in conjunction with Mr. Brodie. It appears, then, from these facts, that the Galvanic energy is capable, under certain circumstances, of supplying the place of the nervous influence; so that by means of its assistance the stomach, otherwise inactive, digests food as usual. Dr. Philip has advanced a step further in the inferences he draws from these experiments, and thinks they establish the "identity of Galvanic Electricity and nervous influence." Our limits preclude us from entering into the discussions of this question, which has given rise to much controversy, and which, although one of great interest, is more of a physiological nature, than appertaining to our present subject. We shall only observe, that although it must be allowed that a considerable analogy has thus been shown to exist between the nervous and Electric agencies, yet it may with great probability be supposed that the Galvanic influence may operate more as a powerful stimulus, exciting the remaining portion of nerve through which it is transmitted to perform such an increase of action, as may compensate for the want of the principal trunk of the nerve.

Analogy between the nervous and Electric agencies.

(102.) Dr. Philip appears also to have succeeded in showing, that the Galvanic influence occasions an evolution of caloric from arterial blood, if the latter be subjected to it as soon as it leaves the vessels; but that it produces no such effect on venous blood. When the lungs and muscles of respiration are deprived of their due proportion of nervous influence, so that their functions are impeded, and the breathing has become difficult and laborious, increased facility is obtained in carrying on these movements, by the stimulus of the Galvanic power. He has therefore proposed its employment as a remedy for asthma, and gives several cases in which it was used with decided benefit.

Galvanism concerned in secretion.

(103.) The probability that animal secretions are effected by the agency of an Electric power operating as in the Galvanic circuit, is an idea that occurred to Dr. Wollaston and to Dr. Young, and which is corroborated by the existence of this power in some fishes, as already adverted to, and by the probability of the universal prevalence of similar powers of lower intensity in other animals, derived from the suddenness with which the nervous influence is communicated from one part to another in the living system. Dr. Wollaston proved by an experiment, that the weakest Electric energies may be capable of producing similar effects to those obtained by powerful batteries, although they would require a time proportionally great; such may, therefore, be the case with animal secretions. The qualities of each secreted fluid, he observes, may hereafter instruct us as to the species of Electricity that prevails in each organ of the body. The general redundance of acid in the urine, for instance, though secreted from blood that is known to be alkaline, appears to indicate in the kidneys a state of positive Electricity; and since the proportion of alkali in the bile seems to be greater than that contained in the blood of the same animal, it is not improbable that the secreting vessels of the liver may be comparatively negative.

It becomes, therefore, an interesting object to inquire, what other organs also may be considered as permanently different in their state of Electricity; and what others may possibly be subject to temporary states of opposite Electrical energies, and may by means of such relation produce the most powerful effects in the animal economy.*

Some experiments on this subject have been instituted by Mr. Brande, but without any very satisfactory result.

(104.) It is scarcely necessary to mention that powerful shocks from a galvanic battery are no less instantly destructive of animal life, than discharges from the ordinary electric battery. Small animals are easily killed by discharges, which would only produce a temporary stunning effect on larger animals.

4. *Circumstances in the Galvanic apparatus on which these effects depend.*

(105.) We have seen that in bodies of high conducting powers, such as metals, the effects produced will depend altogether on the actual quantity of Electricity which is collected in a state ready to be discharged; but it is otherwise in imperfect conductors, such as water, and all organic structures whether of an animal or vegetable nature. The quantity of Electricity which this class of substances is capable of transmitting is limited by several conditions: such as the extent of circuit the Electricity has to perform; and also the degree of intensity at which the Electricity is presented to the conductors. Thus the human body, which follows the same laws as imperfect conductors, is incapable of discharging a Voltaic battery composed of a single pair of plates, however large their surface; because the intensity of the Electricity to be discharged is, in this case, extremely low. As this intensity is augmented by increasing the number of alternations in the pile or battery, so the shock, and other effects on the animal system, follow the same law of increase. This point has been fully established by the researches of numerous experimentalists. It appears to have been first pointed out by Van Marum.†

(106.) The force of the shocks is also much influenced by the nature of the fluid with which the battery is charged. Thus a pile or battery of fifty pairs of plates, with only water interposed between them, will give but a very feeble shock; but if a considerable quantity of salt be dissolved in the water, the shock produced will be much more powerful.

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* *Philosophical Magazine*, xxx. 488.

† Nicholson's *Journal*, i. 177. *Annales de Chimie*, xl. 289.

PART III.

OF THE DIFFERENT FORMS OF GALVANIC APPARATUS.

(107.) We have hitherto, for the sake of perspicuity, confined our attention to one order only of Galvanic combinations, namely, those which are composed of two dissimilar metals, and an oxidating fluid, capable of acting with greater energy on the one metal than on the other; and we have taken, by way of example, the substances most usually employed, namely, zinc, silver, and an acid solution. It will be proper now to consider the variations which may be made in the substances used, as well as in the nature of their combination, so as still to be productive of Galvanic action.

1. *Different kinds of Galvanic circles.*

wo classes Galvanic ments.

(108.) For this purpose the elements of Galvanic combinations have been arranged into two classes, with reference to their powers of conducting Electricity. The metals, together with charcoal, being ranked as perfect conductors; while aqueous solutions, containing air, or saline substances, compose the class of imperfect conductors. The principal metals, or substances composing the first class, arranged in the order of their oxidability, will form the following series, namely, zinc, iron, tin, lead, copper, silver, gold, platina, and charcoal. The fluid conductors most commonly employed, arranged, in like manner, in the order of their power of oxidizing the substances of the first class, will compose the following series, namely, solutions of nitric acid, muriatic acid, sulphuric acid, muriate of ammonia, nitrate of potash, muriate of soda, and other neutral salts; and water containing oxygen gas, or atmospheric air.

alvanic ircles of he first lass.

(109.) A Galvanic circle formed by two of the bodies enumerated in the first series, and one of those belonging to the second, will constitute an arrangement of the first class: and the Electrical effects will be similar to those already stated in the former part of this Treatise, namely, a current of positive Electricity will pass *directly* from the substance which comes latest in the series of perfect conductors, to the one which precedes it; and will be transmitted back again, from the substance which comes first in the series, *through the interposed fluid*, to the one that comes last. Thus, if the circle be composed of gold, tin, and acid, the positive Electricity will pass in the order in which we have here enumerated them, and from the acid will be transmitted back again to the gold. The stream of negative Electricity, will of course follow an order exactly the reverse of that which has now been stated. Thus it appears that each metal is positive with relation to all those that succeed it in the series; negative with relation to those which precede it. It follows also, as a necessary consequence, that the oxidizing fluid, which receives Electricity from the metal that is oxidated by it, and transmits it to the metal upon which it has no chemical action, must be considered as positive with regard to the former, and negative with regard to the latter.

Maximum of effect.

(110.) The powers of the different circles that may be formed by various triple combinations of this kind, are very different in degree; the greatest being that in which two metals, the most remote from each other in the scale, are employed, together with the fluid which acts with the greatest chemical energy on the most oxidable of these metals. It is an indispensable condition for the production of Galvanic effects, that a chemical action be excited between the fluid and one of the metals with which it is in contact. Thus silver and gold evolve no Galvanic influence when in contact with pure water, which is incapable of acting chemically upon either of the metals; but when they are connected with water containing nitric acid, or any other fluid decomposable by silver, they form an active Galvanic arrangement.

Galvanic powers of Charcoal.

(111.) The conducting powers of charcoal, and its efficacy when employed as a component part of Galvanic combinations, were discovered by Dr. Wells.* Sir H. Davy afterwards found that charcoal might be used in the Voltaic circuit, instead of a metallic wire, for decomposing water; carbonic acid being formed by the combination of the oxygen with the charcoal at one pole, and carburet of hydrogen at the other pole. In this experiment, the quantity of gas given out by the former is very inconsiderable, in consequence of its rapid absorption by the water. Sir H. Davy also formed a pile of zinc and charcoal, which acted with considerable energy.

(112.) The fact already stated, that the combination of two metallic bodies with fluids, is productive of Galvanic influence, only in as far as it furnishes two conducting surfaces of different degrees of oxidability, led Sir H. Davy to suspect that a similar agency would be developed if single metallic plates could be connected together by different fluids, in such a manner that one of their surfaces only should undergo oxidation. After many trials he at length discovered that active arrangements might be formed, not only when oxidations, but likewise when other chemical changes were going on in some part of the circle.

Galvanic Circles of the second class.

(113.) If the ordinary Galvanic combinations, in which two perfect comductors are joined with one imperfect conductor, be considered as forming one class of combinations: the second class will consist of those in which one perfect conductor is combined with two imperfect conductors. Of these last, Sir H. Davy distinguishes three different kinds.

First kind.

(114.) The first and most feeble is composed of single metallic plates arranged in such a manner that two of their surfaces are in contact with different fluids, one capable, and the other incapable of oxidating the metal. Tin, zinc, and some other easily oxidable metals act most powerfully in this kind of combinations. If pieces of polished tin, about an inch square and one-twentieth of an inch thick, be connected with woollen cloths of the same size, moistened, some in water, and some in dilute nitric acid, in the following order, tin, acid, water, and so on, till twenty series are put together, a feeble Galvanic battery will be formed, capable of acting weakly on the organs of sense, and of slowly producing the common appearances in water; the wire from the oxidating surface of the plates evolving hydrogen, and the wire from the non-oxidating surface evolving oxygen. When batteries of this kind are placed perpendicularly in the form of a pile, the cloth moistened with acid should be placed underneath the one which is moistened with water; for as the acid is specifically heavier than the water, little or no mixture of the fluid will then take place. When zinc is employed, it is necessary, on account of its rapid oxidation in water containing atmospheric air, to use three cloths; the first moistened with a weak solution of sulphuret of potash, which is possessed of no power of action upon zinc, and which prevents it from acting upon the water; the second moistened with a solution of sulphate of potash, of greater specific gravity than the solution of sulphuret; and the third wetted with an oxidating fluid specifically heavier than either of the solutions. In this case, if the order be as follows, zinc, oxidating solution, solution of sulphate of potash, solution of sulphuret of potash, very little mixture of the fluids, or chemical action between them will take place; and an alternation of twelve series of this kind, forms a battery capable of producing sensible effects.

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* *Philosophical Transactions for* 1798, p. 20.

Second kind.

(115.) The second kind of Galvanic combinations with single plates, is formed when plates composed of a metallic substance, capable of acting upon sulphureted hydrogen, or upon sulphurets dissolved in water, are formed into series, with portions of a solution of sulphuret of potash, and water, in such a manner that one side of every plate is in contact with water, whilst the other side is acted upon by the solution of sulphuret. Under these circumstances, when the alternation is regular, and the number of series sufficiently great, Galvanic power is evolved; and water, placed in the circuit, with silver wires, is acted upon; oxide being deposited on the wire connected with the side of the plate undergoing chemical alteration, whilst hydrogen is evolved from the side in contact with water.

Silver, copper, and lead, are each capable of forming this combination. Plates made from any of these metals may be arranged with cloths moistened, some in water, and others in solution of sulphuret of potash, in the following order, metal, cloth moistened in sulphuret of potash, cloth moistened in water, and so on. Eight series will produce sensible effects; and the wire from the top of the pile produces oxide. Copper is more active in this kind of batteries than silver; and silver more active than lead.

Third kind.

(116.) The third and most powerful kind of Galvanic batteries constructed with fluids and single metals, is formed when metallic substances, oxidable in acids, and capable of acting on solutions of sulphurets, are connected, as plates, with oxidating fluids, and solutions of sulphuret of potash, in such a manner that the opposite sides of every plate may be undergoing different chemical changes; the mode of alternation being regular. The same metals which act in the second form may be used in the third; and the order of their powers is similar. The pile may be erected in the same manner as the pile with zinc under the first head; the cloths moistened with acid being separated from those moistened with solution of sulphuret, by a third cloth soaked in solution of sulphate of potash. Three plates of copper, or silver, arranged in this manner, in the proper order, produce sensible effects; and twelve or thirteen are capable of giving weak shocks, and of rapidly decomposing water: the wire connected with the oxidating end of the apparatus evolving hydrogen; and the wire attached to the end acting on the sulphuret evolving oxygen.

Increa power alterna tions.

(117.) In all the single metallic piles constructed with cloths the action is very transient: but greater permanency may be given to their effects, by a disposition of the plates and fluid similar to the trough of Cruickshanks, with the partitions of the cells, composed alternately of glass, or horn, and of metallic plates, and the cells filled alternately with the different solutions, according to the kind of combination employed: these fluids being connected in pairs with each other by slips of moistened cloth, carried over the non-conducting plates.*

Gener result.

(118.) Sir H. Davy has summed up the general results of these experiments in the following words: "The metals having the strongest attraction for oxygen, are the metals which form the positive pole," (the composite battery being here understood;) "in all cases in which the fluid menstrua act chemically by affording oxygen; but when the fluid menstrua afford sulphur to the metals, the metals having the strongest attraction for sulphur under the existing circumstances, determine the positive pole. Thus, in a series of copper and iron, introduced into a porcelain trough, the cells of which are filled with water or with acid solutions, the iron is positive, and the copper negative; but when the cells are filled with solution of sulphur and potash, the copper is positive and the iron negative. In all combinations in which one metal is concerned, the surface opposite the acid is negative, and that in contact with solution of alkali and sulphur, or of alkali, is positive."†

Form Dr. Y

(119.) Dr. Young also has laid down a general formula for determining the direction of the Electric currents in all Galvanic combinations, which may often be found useful in practice. "We may represent," he says, "the effects of all Galvanic combinations, by considering the oxidation as producing positive Electricity in the acting liquid, and the sulphuration as producing negative Electricity, and by imagining that this Electricity is always communicated to the best conductor of the other substances concerned, so as to produce a circulation in the direction thus determined. For example, when two wires of zinc and silver, touching each other, are separately immersed in an acid; the acid, becoming positively Electrical, imparts its Electricity to the silver, and hence it flows back into the zinc. When the ends of a piece of charcoal are dipped into water and into an acid, connected together in a small tube, the acid, becoming positive, sends its superfluous Electricity through the charcoal into the water. If a wire of copper be dipped into water and a solution of alkaline sulphuret, connected with each other, the sulphuret, becoming negative, will draw the positive Electricity from the copper on which it acts. In all these cases the direction of the current is truly determined, as may be shown by composing a battery of a number of alternations of this kind, and either examining the state of its different parts by Electrical tests, or connecting wires with its extremities, which, when immersed into a portion of water, will exhibit the production of oxygen gas where they emit the Electric fluid, and of hydrogen where they receive it."*

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* *Philosophical Transactions for* 1801.

† *Elements of Chemical Philosophy*, 148.

(120.) Attempts have often been made to form Galvanic combinations without metal. Gautherot asserted that he had succeeded in forming a pile of which charcoal and plumbago were the conducting elements.† Lagrave announced that by placing upon each other alternate layers of muscle and of brain, from a human body, with pieces of moistened cloth or leather interposed, he formed a pile which produced Galvanic effects.‡ Dr. Baconio, of Milan, composed a Galvanic pile entirely of vegetable substances. The substances he employed were discs of red beet root, two inches in diameter; and discs of walnut tree, of the same size, divested of their resin by digestion in a solution of cream of tartar in vinegar. With this pile he produced Galvanic effects on a frog, taking a leaf of scurvy-grass as an exciter.§

(121.) Aldini succeeded in exciting very considerable muscular contractions in frogs, without the intervention of any metallic substance; sometimes by bringing into contact the nerve of one animal with the muscle of another, and at other times by employing the nerves and the muscles of the same animal. In some of his experiments the most powerful contractions were excited, by bringing the parts of a warm and of a cold blooded animal into contact with each other.

Thus on introducing into one of the ears of an ox recently killed a finger of one hand moistened with a solution of salt, and holding in the other hand a prepared frog; when the denuded spine of the frog was made to touch the tongue of the ox, convulsions were produced in the limb of the frog. In like manner, if a prepared frog be held by one hand moistened with solution of salt, and the crural nerves be applied to the tip of the experimenter's tongue, convulsions will be excited.||

Many of these experiments were made in presence of the Members of a Commission appointed by the French National Institute, for the purpose of inquiring into the subject; and they were afterwards repeated in London at the Anatomical Theatre in Great Windmill-street.

(122.) The inference which Aldini drew from these facts was, that a proper animal Electricity was inherent in the body, not requiring the assistance of any external agent for its developement. But the more probable supposition is, as Dr. Bostock has remarked, that the parts of the body in these experiments act in a manner analogous to the pile which was constructed by Sir H. Davy, in which Electricity was developed by the action of two different fluids upon carbon. There are, however, many circumstances wanting to render this analogy complete.*

Of Fishes.

(123.) In the conformation of several fishes, as the *Torpedo*, *Gymnotus Electricus*, and several others already noticed in the Treatise on Electricity, nature has constructed organs appropriated to the excitation of Electricity. These organs have a striking resemblance to the plates of the Galvanic battery; we know nothing, however, of the immediate arrangement from which they derive Electric properties. The effect of the shock they produce, resembles in all respects that of a weak charge of a very large Electric jar; and is therefore exceedingly analogous to that of the Voltaic pile. We have already seen that the shock given by a battery is in proportion to the number of plates of which the series is composed; now, in each of these fishes, there are at least 150,000 cells, a number which will sufficiently account for the magnitude of the effect in giving shocks, compatible with a very low state of Electric intensity. It is presumable, according to Volta, that the small layers or pellicles found in the Electric organs, placed one above the other in the columns, are formed of alternate structures belonging to different classes of conductors, and arranged in such a way as that the heterogeneous parts may be separated by a humid layer of more imperfect conducting power.

2. *Comparison between different batteries of the ordinary construction.*

(124.) Reverting to the more ordinary forms of the Galvanic apparatus, several circumstances with regard to their comparative powers remain to be noticed.

Remarks on the Pile of Volta.

The principal inconvenience attending the pile of Volta, is that it requires considerable time to put together, and adjust it properly; and that it must frequently be taken to pieces and cleaned, on account of the oxidation of the zinc by the action of the fluid employed: operations which become very troublesome when the number of plates is considerable. The soldering together of each pair of zinc and copper plates, is an improvement upon the plan of simply laying them on each other; a better and more extensive contact between the metals being thereby secured. But still the pile is troublesome to put in action; from the fluid being liable to be pressed out of the discs of cloth by the weight of the plates, and frequently running over the edges, and destroying the insulation of the fluid.

The pile has been more in use among the continental philosophers than among those of this country: where the trough, invented by Mr. Cruickshanks, of Woolwich, has almost entirely superseded it. As the fluid can be very readily poured out of the cells, and replaced when wanted, it requires considerably less time to put it in action. The following directions for constructing it are given by Mr. Singer.

Construction of Cruickshanks's trough.

(125.) The zinc plates are made by casting that metal in an iron or brass mould; they may be about an eighth of an inch thick. The copper need not exceed twelve or fourteen ounces to a square foot, and may be soldered to the zinc at one edge only, the other three being secured by cement in the trough. The trough must

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* Young's *Lectures on Natural Philosophy*, i. 675.

† Wilkinson, ii. 184.

‡ *Journal de Physique*, lvi. 235. See also Nicholson's *Journal*, v. 62

§ Nicholson's *Journal*, xviii. 159.

|| Nicholson's *Journal*, iii. 298.

* Bostock, *on Galvanism*, 52.

have as many grooves in its sides as the number of plates it is intended to contain, which should be fewer in proportion to their size, otherwise the apparatus will be inconvenient from its weight. When the plates are not more than three inches square, their number in one trough may be fifty, and the distance of the grooves from three-eighths to half an inch. The trough must be made of very dry wood, and put together with white lead or cement. The plates being put before the fire, the trough is to be well warmed, and placed horizontally on a level table, with its bottom downwards; very hot cement is then to be poured into it, until the bottom is covered to the depth of a quarter of an inch. During this process the plates will have become warm, and they are then to be quickly slided into the grooves and pushed firmly to the bottom, so as to embed themselves securely in the cement. In this way the plates are very perfectly cemented at the bottom, and when this cement is sufficiently cool, a slip of thin deal is to be slightly nailed on the upper edge of one of the sides of the trough, so as to overhang the inner surface about a quarter of an inch. The trough being about three quarters of an inch deeper than the diameter of the plates, there will be an interval between their upper edges and the deal slip; and when the side of the trough to which the slip is attached is laid flat upon the table, this interval forms a channel into which very hot cement is to be poured, and it will flow between each pair of plates, so as to cement one side of all the cells perfectly. As soon as the channel is quite full of fluid cement, the strip of deal is to be taken off, and the trough inclined so as to allow the superfluous cement to run out. When this is effected and the cement cool, a slip of deal is to be nailed on the opposite side, and the same process pursued with that side. The instrument will then be cemented in the most perfect manner, and it may be cleaned off and varnished.*

Objections to it.

(126.) Although the Voltaic trough is a considerable improvement on the pile, yet it is subject to some disadvantages from the action of the liquid on the wood, which becomes thereby warped. The consequence of this is, that the cement, into which the plates are fixed, cracks in various places, and the liquid, insinuating itself into the fissures, soon destroys the insulation. For the purpose of keeping the instrument in order, therefore, the cement must be occasionally run over with a hot iron, which is a tedious and troublesome process.

Troughs of Wedgwood ware.

(127.) A more commodious form for the Voltaic battery is that in which troughs, with a number of partitions, made entirely of Wedgwood ware, are intended to contain the fluid, into which the plates are let down when the instrument is employed. Having already described the construction of this kind of battery, we shall only observe that the most convenient sizes for the plates are from two to six inches square. When a high power is required, a great number of these batteries may be combined together by connecting them in proper order, endwise, with slips of copper: taking care to connect the zinc end of one battery with the copper end of the next, so that the plates shall all tend in one direction.

Objections to them.

(128.) The objections to which the Wedgwood ware troughs are liable, are that, besides being expensive, they occupy a great deal of room, and are easily broken, while the strong affinity of the glaze for moisture soon renders the insulation imperfect, especially if the acidulous exciting liquid be so strong as to occasion effervescence; for in that case, a shower of minute globules is thrown up from the liquid, and falling on the edges of the cells, soon moistens them so completely as to destroy the insulation.

(129.) The power of the instrument, as we have already noticed, is greatly increased by the addition suggested by Dr. Wollaston of having a counterpart of copper to each side of the zinc. Mr. John Hart, of Glasgow, availed himself of this circumstance, in constructing a battery in which the inconvenience above stated is entirely avoided. It occurred to him, that by adding sides and bottoms to the double copper plates, they would themselves form cells for containing the acidulous liquid, and the use of troughs be thus altogether dispensed with. The cells are formed by cutting the copper in the form represented by fig. 14; they are then folded up, as seen in fig. 15, and the seams grooved. A drop of tin is run into each lower corner to render the cells perfectly tight, and at the same time to increase the positive state of the copper. Fig. 16 represents the zinc plate cast in the usual manner, and having a piece of screwed brass wire cast into the top of it in order to suspend it by. Fig. 17 is a section of the battery, showing how the copper tail of the first cell is connected with the zinc plate of the second, and so on. This connection is rendered perfect by joining them with a drop of solder. The zinc plates are kept firm in their place by three small pieces of wood. The whole are then fixed (by means of screw-nuts fitted on to the brass wires) to a bar of baked wood, previously well varnished. When the battery is to be used, it is to be lifted off the frame, and dipped into a wooden trough lined with lead, into which the acid has been poured, or it may be placed into the leaden trough, and the liquid poured into it, till the cells are full. It is then to be placed on the frame, and the rest charged in succession. When the battery is small, two may be suspended on one frame. When used for shocks, they may be arranged with the positive and negative poles together, and joined with wire to complete the circuit; but when employed for deflagration, the batteries ought to be placed alongside of each other, with all the positive poles at one end, and the negative at the other, and the poles of the same name joined: this arrangement will increase the surface while the number is the same.

(130.) A battery of this construction made by Mr. Condie, with ten triads, when compared with one upon the plan of Dr. Wollaston, made by Mr. Newman, with the same number of triads, but of double the surface, was found to decompose the same quantity of water in less time than the latter, thus indicating a very considerable superiority of power: a result which can be attributed to nothing but its superior means of insulation.*

(131.) In making experiments in which numerous repetitions of contact between wires are required, Mr. Faraday recommends, if these wires be of copper, to rub the ends over with a little nitrate of mercury; an amalgam is thus formed on the surface of the copper, which does not oxidate or become dirty, as copper itself does, but remains bright, and fit for Voltaic contact for a long time.*

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* *Elements*, 324.

* *Edinburgh Journal of Science*, iv. 19.

3. *Results of various analyses of the Voltaic pile.*

(132.) Our attention has hitherto been directed to the effects resulting from the conjoint operation of the Galvanic apparatus, of which all the adjoining parts, constituting the compound circles, are in extensive contact. But in order to obtain correct views of the theory of Galvanic action, it is necessary to ascertain the precise relation which each part of the apparatus bears to the effects produced; or the function that it performs in the process which results from the combination employed. The investigations of M. de Luc were directed to this important inquiry. He began by considering the Voltaic pile, consisting of its three constituent parts of zinc, copper,† and moistened cloth, following each other in successive alternations, as divisible into ternary groups, under three different aspects. First, zinc, wet cloth, and copper; secondly, copper, zinc, and wet cloth; and thirdly, wet cloth, copper, and zinc. In order to discover which of these ternary associations constituted the efficient part of the apparatus, he united them respectively into piles, in each of which the different groups were separated from each other by some conductor, which could not be supposed materially to influence the effects. For this purpose M. de Luc employed small tripods, formed of brass wire so bent as to touch the plates, between which the tripod was placed, only at the three points of support. Thus was the pile *dissected*, as he terms it, by three different modes, so as to compose three different instruments. To each extremity of these piles a delicate electrometer was attached; and the opposite poles were also connected by the interrupted wire passing through water, so that both the Electrical and chemical effects could be measured at the same time: care was also taken that each pile should, in other respects, be insulated. The following are the principal results of the experiments conducted with this apparatus.

(133.) He first examined the phenomena presented by the first dissection of the pile, in which the groups were arranged with the fluid between the two metals, while the surfaces of the metals, which in the ordinary pile are in contact, were separated by the brass tripods. He found that the pile, when dissected in this way, acts in the same manner, both as to the Electrical and chemical effects, as if all its parts were continuous, except that its power is rather diminished by the separation of the metals.

(134.) When dissected according to the second mode, in which the two metals were placed together; and the wet cloth was in contact with the zinc, but separated from the next plate of copper by the brass tripod; the extremities of the pile indicated to the electrometer the same states of positive and negative as in the ordinary pile; but no shock was experienced when the circuit was attempted to be made through the human body. No decomposition of water took place when the wires of the interrupted circuit were placed in water; although from the cessation of all Electrical indications, it was evident that the Electricity was conducted through them.

Third dissection.

(135.) In the third dissection of the pile, the ternary groups consisting of the zinc and copper in mutual contact, the moistened cloths being in contact with the copper, and the groups being separated, as before, by the brass tripods, it was found that no effect, either Electrical or chemical, was perceptible.

Second series of Experiments.

(136.) In these experiments, the cloths were moistened with water only; but a second set of experiments were next performed, in which a strong solution of muriate of soda was employed instead of water. With the continuous pile, no difference was observed with regard to the effects upon the electrometer by this substitution; but a more powerful sensation was produced when the salt was used. A new shock was experienced every time either of the hands was brought into contact with the apparatus, or removed from it; but no sensation was experienced as long as they remained in contact. When the interrupted circuit was applied between the extremities of the pile, the shock was felt, but in a less degree; and the chemical effects were suspended, while the contact of the body was preserved: evidently showing that the body is about an equally good conductor with water.

The pile with the cloths soaked with brine, was now dissected in the same three ways as before. In the first dissection, that is, with the moistened cloths between the plates, the same Electric effects were exhibited by the electrometer, the same shock was felt, and the same chemical effects were produced, only in rather a less degree than with the continuous pile formed with muriate of soda. The second and third dissections of the pile produced exactly the same effect, as when the same dissections were employed with pure water.*

Distinct sources of Electrical and Chemical powers

(137.) The general conclusion which M. de Luc deduced from these comparative experiments is, that the Electrical and the chemical effects originate from different parts of the pile, or from different groups, considered in relation to the parts contiguous to them. The Electrical effects appear to arise simply from the combination of the two metals, each pair being separated by a fluid conductor; while for the chemical effects ternary groups are necessary, consisting of the two metals with a fluid between them. This distinction between these two sets of properties, or modes of action, is supposed to be proved by the different effects of the pile in its three states of dissection. In its first state, which may be regarded as equivalent to the continuous pile, it exhibits both the Electrical and the chemical action: for here the two metals are in contact with each other, either directly, or by the intervention of the brass frames, which is the condition requisite for the Electrical effects; and they are also separated by wet cloth, which is the condition requisite for the chemical effects. In the pile dissected in the second manner, there are the binary groups, that is the metals in contact, for producing the Electrical effects; but as there is no fluid between them, we obtain no chemical effect. In the third dissection, neither of the conditions just stated are preserved, and no effects result: the metals have not the wet cloth between them, and cannot therefore produce any chemical effect; and the Electric current is prevented by the zinc plates having copper on one side, and the brass frames on the other, both of which have the same Electrical relations to the zinc, and must therefore counteract each other.

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* *Journal of Science*, xii. 185

† In the original experiments of De Luc, silver is used instead of copper; but we have preferred mentioning the latter metal for the sake of preserving uniformity with preceding statements.

* Nicholson's *Journal*, xxvi. 113—130.

Oxidation required for the Chemical power.

(138.) The observation of the differences of effect which took place when a saline solution was employed instead of pure water, led M. de Luc to examine what connection existed between the chemical action of the instrument and the oxidation of the zinc. With this view he formed a pile of pewter and silver; the pewter being chosen for the experiment, because it has an Electrical relation with silver, and is oxidable by muriatic acid, at the same time that it is not much affected by pure water. In the first instance water was interposed between the plates; the extremities of the piles, as indicated by the electrometer, became Electric, the pewter side negative, and the silver positive; but there was no shock, nor any decomposition of water in the interrupted circuit. A pile was then formed of such a number of zinc and pewter plates, that its Electrical energy might be the same with the pewter pile; but here there was both the shock produced and the decomposition of water. The pile of pewter and silver was then fitted up with muriatic acid; and in this case, when the pewter plates became oxidated, the shock and the decomposition of water were both produced. Hence he concludes, that when the metal is not oxidated, no chemical effect is produced on the water in the interrupted circuit. When the oxidation is produced by means of pure water, there is no shock, although the chemical effects take place; and lastly, when either of these effects are produced, the current of Electricity is retarded in its passage across the water in the interrupted circuit.*

4. *Phenomena of the Electric Column.*

Invention of the Electric column by De Luc.

(139.) We have also to notice, in this place, the curious properties of an instrument which resembles the Voltaic pile in the successive and regular alternations of dissimilar metals, and of imperfect conductors, of which it is composed; but which differs from it in the latter consisting of dry, instead of fluid substances. This instrument was invented by De Luc, while he was engaged in the train of investigation of which we have given the results; and in order to distinguish it from the Voltaic pile, he gave to it the name of *the Electric column*. He was led to its construction, by the trials he made to ascertain how far a liquid was essential to the operation of the pile; and by finding that Electrical effects were still produced when the pile was mounted with pieces of cloth not moistened at all: although these effects were in that case weaker than if the cloths were wetted. He then commenced a series of experiments, in which he substituted layers of different animal and vegetable substances for the wetted cloths, interposed between the metals. He found writing paper to be the most convenient of all the materials which he tried. A column constructed with the two metals arranged in pairs, with discs of paper between each pair, was found to give the same Electrical indications as the common Voltaic pile; the end of the column which is bounded by the zinc plate being in the state of positive Electricity; and that bounded by the copper plate, in the negative state. But, however numerous the plates, it produced no chemical effects; nor could any oxidation of the surface of the zinc plates be perceived to have taken place, even when the instrument had been for a long time in action.

(140.) In order to obtain any considerable effect from this instrument, it is necessary that it should contain a very considerable number of plates. As the thinnest surface of copper is adequate to the purpose answered by that metal, a trial was made with what is called Dutch gilt paper, which consists of thin copper leaf, laid upon paper, together with tinned iron plates. Eight hundred groups thus composed, and regularly arranged, were included in a glass tube; and formed an instrument which affected the electrometer more powerfully than a Voltaic battery of an equal number of plates; but yet, notwithstanding, produced no chemical effects whatsoever. Plates of zinc were afterwards employed instead of the tinned iron, as being both more convenient and efficacious.*

(141.) Mr. Singer, who has had extensive experience in the construction of these columns, in all the variations of which they are susceptible, gives the following directions for making them. Of the materials to be employed he gives the preference to thin pieces of flattened zinc, alternated with writing, or smooth cartridge paper, and silver leaf. The silver leaf is first laid on paper, so as to form silver paper, which is afterwards cut into small round plates by means of a hollow punch. An equal number of plates are to be cut from these flattened pieces of zinc, and from common writing or cartridge paper. The plates are then to be arranged in the order of zinc, paper, silvered paper with the silvered side upwards; then zinc, paper, and so on; the silver being in contact with the zinc throughout; and each adjacent pairs of the metals separated by two discs of paper from each other. An extensive arrangement of this kind may be supported by being placed between three slender glass rods, covered with sealing-wax, and secured in a triangle by being cemented at each end into three equidistant holes in a round piece of wood: or the plates may be introduced into a glass tube previously well dried, and having its ends covered with sealing-wax, and capped with brass; one of the brass caps may be cemented on, before the plates are introduced into the tube, and the other afterwards. Each cap should have a screw passing through its centre, and terminating in a hook outside. This screw will serve to press the plates closer together, and to secure a perfect metallic contact with the extremities of the column.†

(142.) By placing two of these upright columns side by side, but with their poles in opposite directions, and connecting their upper ends, the whole apparatus becomes equivalent to a column of double the length, of which the two lower extremities become the efficient poles. If each of these extremities be insulated, and made to terminate in a small bell; and a brass ball be suspended as a pendulum by a silk thread, so as to hang midway between the bells, and at a very on the other hand, this action is resumed when the layer of paste has recovered its moisture, by attracting it from the atmosphere. Like the Electric column, it charges the condenser by a simple contact; and it preserves this property for whole months and years: but it does not excite shock, nor taste, nor chemical action.

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* Nicholson's *Journal*, xxvi. 241. In the above account of De Luc's paper, we have chiefly followed Dr. Bostock's abstract contained in his valuable work on Galvanism, 82.

* Nicholson's *Journal*, xxvii. 83.

† Singer, 452.

Pile of Zamboni.

(147.) Professor Zamboni also of Verona, constructed a species of pile, of which the Electrical effects were said to be very durable. It was composed of discs of paper, gilt, or silvered on one of their sides, and covered on the other with a layer of pulverized black oxide of manganese, mixed with honey. A similar pile has also been constructed with the omission of the honey.* This instrument exhibits signs of the Electrical influence in the same manner as the pile of paste; but not any chemical action, nor taste, nor shock. The Electrical attractions and repulsions which it produces are very considerable in their degree; for if two of these piles be placed at a distance of four or five inches from each other, and a metallic needle be properly suspended between them, it will be alternately attracted by the two piles, so as to move between them like a pendulum. When Zamboni's pile is confined for a short time in a limited portion of air, the oxygen of the air is absorbed by it, and after this has happened the action of the pile ceases. When the oscillations of the pendulum have stopped, on admitting a fresh supply of atmospheric air, without moving the apparatus, the pendulum was instantly attracted to the positive pole, and the oscillations renewed in the same manner as at first. These oscillations were not found to be affected by atmospherical changes, as those of the Electric column.†

Its comparative powers.

(148.) In a Memoir relative to the dry Voltaic pile, Zamboni states that its energy ceases to diminish after two years; such, at least, he finds to be the case during an experience of twelve years. The diminution in the two first years varies according to the manner in which the pile is constructed. The pile is more energetic in summer than in winter, both with regard to the intensity produced, and the promptitude with which it is manifested. The tinned paper, called silvered paper, with black oxide of manganese, developes an Electric force very superior to that obtained from paper covered with a thin leaf of copper, as in what is called Dutch gold paper. By using a dry pile of one thousand pairs, the plates being about two inches in diameter, Zamboni obtained by the condenser sparks of an inch in length; so that with such a pile, the Electric battery might be retained constantly charged to a state of tension, which might be heightened at pleasure, by increasing the number of plates. He is of opinion that a pile of 50,000 pairs of plates, of the usual diameter, of leaves of tinned paper, would be a constant source of Electricity, of which the tension would equal that of a strong common Electrical machine.*

6. *Of the Secondary Piles of Ritter.*

(149.) While attempts were making to construct Voltaic instruments composed entirely of dry substances, Ritter, of Munich, invented a construction, which, indeed, had not the power of developing Electricity by its own action, but was capable of receiving a charge from the Voltaic pile, so as thereby to acquire for a time all the properties of the pile. These have been denominated the *Secondary Piles of Ritter*. They consist simply of a column formed of discs of copper, and moistened card, placed alternately. When a pile of this description is once charged, it loses its Electricity very slowly, when there is no direct communication between its two poles. But if this communication be made by a good conductor, a discharge will immediately take place of the Electricity accumulated in the exterior plates, which, as in the Leyden jar, will operate by an instantaneous shock. To this effect a new state of equilibrium will succeed, and the discharges may be repeated a considerable number of times, but of course with continued diminution of power, until they at length cease to be sensible.

(150.) This apparatus produces, with diminished intensity, the decomposition of water, and the other physical, chemical, and physiological effects obtained from the ordinary pile.†

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* Biot, *Traité de Physique*, ii. 540; and *Journal of Science*, ii. 451.

† *Journal of Science*, ii. 161.

* *Annales de Chimie*, xxix. 198.

† Biot, *Traité de Physique*, ii. 542.

PART IV.

THEORY OF GALVANISM.

(151.) Having given an account of the principal phenomena which relate to this science, as they present themselves to observation, without any reference to the theoretical views of the experimentalists who discovered them, or to the hypotheses which they may tend either to support or to confute: we have now to consider what are the general laws to which they are reducible, and what explanation these laws will enable us to give of the various circumstances attending these phenomena.

(152.) The proofs of the identity of the agencies producing Galvanic and Electrical phenomena, may easily be collected from the facts we have already detailed. All the effects which the Electric battery is capable of producing, may, as we have seen, be also produced by the Voltaic battery. The shock and convulsive muscular actions which accompany its discharge through the human body; the vivid spark and loud report which mark the transit of Electricity through the air; the ignition and deflagration of metals; the inflammation of gunpowder, phosphorus, and mixtures of hydrogen and oxygen gases, are effects common to both these instruments. All those bodies which are conductors of Electricity, are also conductors of Galvanism; as the metals, charcoal, and those liquids which contain oxygen as one of their elements. The Galvanic, as well as the Electric shock, is propagated through a number of persons without any perceptible interval of time. We have also decisive evidence of the evolution of Electrical influence in all Galvanic combinations, by applying to them the test of the condensing electrometer, which is then affected in the same way as by ordinary Electricity. The Electrical charge which a Voltaic battery communicates to a Leyden jar, is also an unequivocal proof of the presence and active agency of Electricity in the poles of that instrument. A difference, indeed, was supposed to exist between the Galvanic and the Electric batteries in respect to the phenomena of their discharge; as the former seemed to have no *striking distance:* but this apparent discordance was removed by Mr. Children, who, by employing a powerful apparatus, to which a micrometer was attached, ascertained that the Galvanic spark was capable of passing through a certain space between the extremities of two platina wires.* The chemical decompositions, which result from the agency of Galvanism, in substances through which the circuit is made to pass, appeared, also, for a long time, to constitute an essential difference in the mode of action of these two principles, and to be an effect peculiar to Galvanism; but the researches of Dr. Wollaston have removed even this ground of distinction, by proving that the same effects may be likewise obtained by the agency of ordinary Electricity, when a proper apparatus is employed. These important experiments, which have already been sufficiently detailed, (sec. 77, 78,) have completed, in the most satisfactory manner, the chain of evidence which has incontrovertibly established the identity of Galvanism and Electricity.

Part IV.

Differences in other respects.

(153.) While there exists this perfect similarity in Galvanic and Electrical effects, with regard to kind, there are many circumstances in which they differ with regard to degree, to continuance, to the relative proportion which they bear to one another, and to the combinations in which they are found to occur. We have already noticed some of these principal features of difference, while describing the several effects of Galvanism; and have pointed out many particulars, in which they even present a striking contrast with the ordinary operations of Electricity. We are now, therefore, prepared for pursuing our generalization of facts to a further extent; and for entering into an inquiry into the nature of these different modifications of effect, and the sources from which they proceed.

1. *Modifications of Galvanic Power.*

Distinction between Quantity and Intensity.

(154.) There are many physical powers, in regard to which it is necessary, for the proper estimation of their effects, to distinguish two different modes of efficiency: the one of *absolute quantity;* the other of *intensity.* The first has reference to the totality of effect which the power in question is capable of producing, from first to last, when the whole of that power is exerted, and actually expended in the production of its proper effect. The second of these terms is expressive of the degree of effect produced with relation to circumstances which limit the operation of the power in certain ways, so as to allow only of its partial exertion. Heat, or caloric, is a power, the operations of which cannot be understood or appreciated unless this distinction between its quantity and its intensity be kept in view. The quantity of absolute heat which a given body contains would be measured by the quantity that could be abstracted from it by surrounding bodies, which were themselves absolutely deprived of heat; or which it would lose by radiation, under circumstances in which it could receive no heat in return. The intensity of the heat residing in a body, is the tendency it has to quit that body, and either pass into those other bodies which are in contact with the first, or diffuse itself in space by radiation. This quality of intensity in heat is expressed by the term *temperature;* which, when applied to a heated body, may be defined the actual disposition of that body to part with its heat. It is well known that in bodies of different kinds, the temperatures may be in very different ratios to the absolute quantities of heat. Two bodies, however different may be their absolute quantities of heat, are said to be of the same temperature, or, in other words, their heat to be of the same intensity, when the dispositions in each to impart heat to the other are precisely equal; that is, in which the tendencies of the heat to escape from each are the same, and the radiations exactly balance one another. Temperature, or intensity of heat, depends upon the nature of the substances in which it resides, and its attraction for that substance, as well as upon the absolute quantity of heat; and is, therefore, subjected to a very different law. The ratio between the absolute quantity of heat which a body contains, and its temperature, is expressed by the term *capacity for heat.*

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* *Philosophical Transactions for* 1809, p. 36.

(155.) A distinction precisely similar must be made with regard to the operations of Electricity. The prime conductor of a common Electrical machine, when communicating with the ground, is in a neutral state, and exhibits no signs of Electricity. If it be insulated, and the machine set to work, a certain quantity of that power will be communicated to it; which power will affect bodies in the vicinity, and will at the same time possess a tendency to fly off from the conductor. It is this tendency to produce certain effects on other bodies, and to quit the body which contains it, that is termed *intensity;* and although it be true, that when all the circumstances relative to the conductor and the surrounding bodies are the same, the intensity will increase in a certain ratio with the absolute quantity of Electricity that has been given to the conductor by the machine, yet if those circumstances vary, the same ratio is not preserved. If, for example, the form of the conductor be altered, by drawing out one part into a point, the intensity of the Electricity at that part will be increased in a high degree, while the absolute quantity in the conductor remains the same as before. On the contrary, if, while the general form of the conductor remains the same, its surface be increased, the same quantity of Electricity will be diffused over a more extended space, and will exist in a state of diminished intensity. The term intensity with respect to Electricity, corresponds, therefore, to temperature as regards heat; and expresses in both cases the tendency of the agent to quit the body which contains it. We have a striking illustration of the difference between quantity and intensity in the Leyden jar; the coatings of which are capable of receiving, and of retaining a very large quantity of Electricity, in consequence of the law of induction. Hence, although the quantity be great, the intensity is very small; and the instrument may in this sense be considered as having a great *capacity* for Electricity.

Conducting power.

(156.) Besides quantity and intensity, there is also a third regulating condition to be taken into account in estimating the effective agency both of heat and of Electricity; namely, the *conducting power.* The time which a given body will take to have its temperature changed from one degree to another, when subjected to the operation of a heating or cooling cause, will depend not merely on its capacity for heat, but also on the facility with which heat is transmitted from particle to particle. The quickness of dissipation, or of absorption, will be much promoted by the ready passage of the heat to every part of the body which undergoes a change of temperature; or, in other words, it will be regulated by the degree of conducting power possessed by that substance. A body charged with Electricity will, in like manner, act with greater quickness or slowness in producing Electrical effects, in proportion to the facility with which the Electricity can be transferred along its parts; a facility which is the result of its conducting power, and which may be expressed by the general term of *velocity.*

(157.) For the production of different kinds of effects by Galvanic combinations, different modifications of the Electric power with respect to quantity, intensity, and velocity are required. Thus, the increase of temperature, the ignition and deflagration of metals, and all Electro-Magnetic effects, are in proportion to the *quantity* of transmitted Electricity: the affection of the condenser and of the electrometer, and the charge communicated to the Leyden jar, depend solely on its *intensity:* the shock and other physiological effects are the results principally of intensity, but partly also of quantity: the power of effecting chemical decompositions requires, in addition to quantity and intensity, a certain degree of *velocity* also, for its production. It is for want of the production of a sufficient quantity of Electricity in a given time, that the common Electrical machine fails, under ordinary circumstances, in producing chemical decompositions. When this is obviated, as in Dr. Wollaston's apparatus, we find it rendered effectual in producing chemical action. It is from deficient intensity, on the other hand, that a single pair of plates, even when of considerable size, as in the calorimotor, affords no chemical effects in the interrupted circuit. On the contrary, it is the imperfection in the conducting power, that is, in the velocity of the current, that is the source of the incapacity of the Electric column of De Luc, or the other forms of the dry piles, such as those of Zamboni, for producing any sensible chemical changes in fluids which are interposed in the circuit.

2. *Sources of Galvanic Power.*

(158.) The preceding observations apply only to the transmission and distribution of a power already existing in bodies; but the circumstances attending the origin and production of such a power present a distinct subject of consideration. In this point of view the parallel which we have drawn between heat and Electricity is no longer preserved. Heat is a positive quality; and cold is merely the absence or abstraction of that quality. Many processes, both of a chemical and mechanical nature, are attended with the evolution of heat; that is, with an apparent addition to the positive quantity of heat which existed prior to such change. In such a case one of two things must have happened: either a quantity of heat, which had before been inactive, is rendered active, or liberated, as it were, from the restraint of some controlling power; or else a quantity of heat, which did not before exist, has been actually generated. Any sudden diminution of capacity, such as that which attends the combination of sulphuric acid with water, is an example of the first kind; the production of heat by friction is an instance of the last. But in both cases the heat so evolved appears to be a positive addition to the quantity existing in the bodies concerned; and we find no corresponding abstraction of heat, that is production of cold, in any other quarter, as a compensation for the appearance of this heat in the body which evolves it. The phenomenon does not consist in the mere transfer of this power from one place, whence it is withdrawn, to another place wherein it is accumulated.

The series of experiments by which these important results are established, was repeated by Volta, and verified in presence of a Commission of the Members of the French Institute. The following is the outline of the principal experiments, for a more detailed account of which, the reader is referred to the report of the Commissioners drawn up by Biot.*

Volta's experiments on this subject.

(165.) The apparatus employed by Volta for these experiments, consisted of two discs, the one of zinc, the other of copper, rather more than two inches in diameter, ground perfectly plane, not varnished, and having in their centres insulating handles perpendicular to their surfaces, by means of which the plates could be brought into contact, without being actually touched with the hand. With this precaution the discs were made to approach till they touched one another; they were then separated, by keeping them parallel while they were drawn back. The Electricity they possessed after this separation was then examined by means of the condenser; and that the effects might be rendered more distinct, the Electricity produced by a number of successive contacts, (taking care to restore the discs to their natural state after each contact,) was accumulated in the same condenser. It was invariably found that the copper disc charged the condenser with negative, and the zinc with positive Electricity. Thus these two metals, insulated, and in their natural state, are brought by their simple contact into different Electrical states; the zinc acquiring an excess of positive Electricity, and the copper the complementary quantity of negative Electricity.

(166.) This experiment may be varied in the following manner: Instead of making one of the plates of the condenser communicate, as is usual, with the ground, leave them both insulated upon the electrometer; but every time that the discs are separated after contact, touch with each of them, and always with the same, each of the plates of the condenser. After several contacts of this kind, separate the plates, and each of them will be found charged with that species of Electricity belonging to the plate with which it was touched. All these experiments require great care and attention to ensure correct results. The electrometer and the insulated disc of the condenser should be very perfectly insulated, and the manipulations very carefully conducted.†

Cause of this transfer unknown.

(167.) If it be asked, What is the cause of these phenomena? we fear it must be confessed that no satisfactory solution of the question has as yet been given. They do not accord with any of the previously known laws of Electric equilibrium, and appear to be totally at variance with every preconceived notion we might have entertained of the results of any disturbance of that equilibrium. We must, therefore, for the present content ourselves with admitting that some unknown cause exists, which upon the contact of zinc and copper, determines the transfer of the positive and negative Electricities respectively to the two surfaces which are brought in apposition, and which continues to maintain this relative difference of Electrical states as long as the contact is continued, and as often as it is renewed.

(168.) The two Electricities appear to be retained on the surfaces of the two metals which are in contact in a manner in some respects analogous to the Electrical condition of the two coatings of a Leyden jar. Each respectively is prevented from exhibiting Electrical effects by the inducting influence of the Electricity contained in the other. But if a communication be made between them, the equilibrium is immediately restored. But in the case of the zinc and copper no reason has been assigned for the difficulty which opposes the direct transit of the Electricity through the surfaces of contact.

(169.) Another question of great importance next presents itself. Are the positive and negative Electricities, collected at the two contiguous surfaces, so concentrated in those surfaces as not to produce any sensible Electrical effects at a distance from the surface? Or does the greater vicinity of the one or the other determine some degree of Electrical polarity in the conjoined metals? If such were found to be the case, the intensity of the sensible Electricity would, it is evident, be extremely low, compared with the total quantity retained; for the same reason, that the coatings of the Leyden jar exhibit but a feeble degree of Electrical intensity. Volta has endeavoured to establish the fact that some degree of Electricity is perceptible in the different metals, even when they continue conjoined. For this purpose he formed a thin metallic rod by joining two pieces, the one of zinc, the other of copper, and soldering them end to end; then taking between the fingers the extremity which was composed of zinc, he touched with the copper extremity the upper plate of a condenser, which was also of copper, while the under plate of the condenser communicated with the ground. After the contact, the plate which had been touched, was found to be electrified negatively. In order that the Electricity thus produced by a single contact may be very apparent, the condenser must be much larger than that of the electrometer, and its condensing power considerable.

(170.) This experiment was repeated in a reverse order. That extremity of the rod, which was of copper, was now taken between the fingers, and the upper plate of the condenser, which, as before, was of copper, was touched with the zinc extremity of the rod. On removing it, and examining the plate of the condenser, it was found not to have acquired any Electricity whatsoever. If the rod had consisted of zinc alone, it would have acquired positive Electricity from the copper plate of the condenser by its contact with it, and the condenser would have been rendered negative. But the addition of the piece of copper to the remote end of the zinc rod, was sufficient to prevent this effect from taking place, by having already communicated a positive charge to the zinc. These experiments, therefore, appeared to show that the force which determines a transfer of positive Electricity from the copper to the zinc on one side, may be balanced by a similar force acting on the opposite side of the zinc. In the first experiment, in which the two pieces of copper were on the same side of the zinc, this force was allowed to exert itself, and the Electricity which it disengaged was spread over the plate of the condenser. But in the second experiment, in which the zinc was situated between two masses of copper, this force was exerted equally on the two sides of the zinc, and therefore did not develope any Electricity.*

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[*] See also his *Traité de Physique*, ii. 471.

[†] See Singer's *Elements*, p. 316.

[*] Biot, *Traité de Physique*, ii. 472—474.

cate with the ground, neutrality is immediately given to that extremity; and the opposite end has its Electrical state increased to twice the degree it before possessed. The converse will take place if the communication with the ground be made with the other pole, instead of the former one.* The effects which we have detailed in the former part of this Treatise, as being produced on bodies which form part of the circuit connecting the two poles of the battery, both when those bodies are metallic, (in which case a rise of temperature, and Electro-Magnetic effects take place,) and also when the bodies are imperfect conductors, such as organized bodies, and liquids holding various chemical substances in solution, are readily accounted for by the passage of the continued stream of Electricity determined from the one pole of the battery to the other. The differences of effect are explicable by the differences in quantity, intensity, and velocity, arising out of the different forms and modifications of the apparatus.

(177.) According to this theory, then, the source of all the Electricity obtained by the Galvanic apparatus is at the surface of contact of the dissimilar metals; while the fluid part of the circle performs no other function than that of a conductor of this Electricity from one metallic surface to the other. The circumstance which determines the *quantity* of Electricity, is the extent of the surfaces of metal in actual contact: that which produces the *intensity*, is the number of alternations of the three elements of the circle: that which gives *velocity*, is the degree of conducting power in the fluid part of the circle.

Influence of the conducting power of the fluid part.

(178.) It will be perceived, that the chemical action exerted between the fluid and the metals is regarded, in this theory, as in no way concerned with the production of Galvanic effects. It is considered as an accidental circumstance, generally accompanying indeed, but having no immediate influence on the Electrical phenomena. The power of the battery is increased, it is true, by fluids which exert a strong chemical action on the most oxidable metal, and particularly by acids, and bodies containing oxygen capable of uniting with the metal, such as atmospheric air, (sec. 75:) but all these substances, it is alleged, also increase the conducting power of the liquid, and it is in consequence of this latter property, and not from the chemical changes they produce, that the Electricity is made to circulate with increased rapidity. The effective quantity of Electricity will be regulated almost entirely by the conducting power; for the quantity actually evolved by the contact of the metals, is incomparably greater than that which the liquid conductors, under ordinary circumstances, can discharge.

The intensity not increased by it.

(179.) If the chemical action of the liquid had any share in the Electric effect, we should expect that the intensity as well as the quantity and velocity of Electricity, would be augmented by an increase of chemical action; whereas the increase of conducting power would produce only an augmentation of velocity, and could increase neither the absolute quantity, nor the intensity of the Electricity. In confirmation of this latter view of the subject, an accurate comparison was instituted by Biot, with the aid of the condensing Electrometer, of the charges obtained from piles of the same number of plates, constructed with moistened conductors of different kinds; and it was found that water, weak acids, the greater number of saline solutions, the substances in general whose conductibility is powerful, give, as nearly as can be judged, the same quantities of free Electricity, that is, Electricity of the same intensity, and give it also by a contact to our senses instantaneous.* We may even, with most of these conductors, increase or diminish extremely the extent of their surfaces, without producing any sensible variation in the charge of the condenser, owing to the facility, almost infinite, which their surfaces present to the transmission of the Electrical currents.† But this tends to prove that, in every case, they only act the part of conductors, and that the contact of the elements of the pile, and not their chemical action, is the determining cause of the production of the Electricity.

(180.) But it is further maintained, that even the absolute quantity of Electricity evolved, is not in proportion to the chemical action; for sulphuric acid acts as powerfully on zinc as the nitric or muriatic acids, but is less active in exciting the chemical powers of the battery, which, we have seen, depend on the quantity of Electricity. In like manner, the alkalies, which exert but a very inconsiderable chemical action on the metals, excite its powers in a greater degree than many saline fluids, of which the chemical energies are much greater.‡

(181.) Against this theory, which is generally denominated the Electric theory of Galvanism, in contradistinction to the one which will presently be stated, and which has been called the Chemical theory, many formidable objections may be urged. The truth of the fundamental proposition on which the whole of it rests; namely, that while two dissimilar metals remain in contact there is a force in constant operation, which tends to separate the two Electricities, and impel them in opposite directions, is itself exceedingly questionable. If such a force were really to exist, it would differ from all the other known powers in nature. All the powers and sources of motion, with the operation of which we are acquainted, when producing any of their peculiar effects, are expended in the same proportion as those effects are produced; and it is from this circumstance that there arises an impossibility of producing by their means a perpetual effect, such as, for instance, a perpetual motion. But the Electromotive power which Volta ascribes to the metals, as resulting simply from this contact, is a force which, as long as the Electricities impelled by it are allowed to escape, is never expended, but continues to be exerted with undiminished power in the production of a never-ceasing effect. The improbability of such a supposition is almost infinite.

(182.) Secondly, the proposition that positive Electricity has a tendency to quit a plate of zinc, and negative Electricity to quit a plate of copper, while these two metals are kept in contact, cannot by any means be inferred from what takes place after the separation of these metals. Whatever displacement of the two Electricities may attend the approximation or contact of the metals; they must both be retained at the surfaces of contact, by the law of induction, and can have no tendency to quit those surfaces until the pears completely extinguished; but the letting in a small quantity of oxygen is sufficient to revive it.[*] These facts were indeed denied by Volta; but they have been ascertained beyond all doubt by the researches of Haldane, Pepys, Biot, Van Marum, and many others. Biot has endeavoured to explain them upon the Voltaic theory, by ascribing the diminution of effect which takes place in the pile after a certain time, to the transfer of a portion of the oxide of zinc through the fluid to the surface of the copper, where it is deposited, and sometimes revived; whenever this last effect is produced, it gives rise to an Electromotive force in a direction opposite to that which the apparatus was at first calculated to create, and which is thereby greatly weakened, or completely neutralized. The revival of the action of the pile by the readmission of oxygen, he conceives to be owing to the latter insinuating itself between the pieces of cloth, and uniting with a portion of zinc, which it detaches in the form of oxide. This oxide of zinc, being attracted to the copper surface, is transferred thither, and carries along with it the Electricity with which the zinc plate had been charged; and this motion of transport, he says, continued from one end of the pile to the other, will reestablish the transmission of Electricity.[†]

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* Singer's *Elements*, p. 426.

* Biot, *Traité de Physique*, ii. 487.

† Ibid. p. 489.

‡ Singer, *Elements*, p. 431.

(188.) Even in the Electrical column of De Luc, the oxidation of the metals appears to be essential to its activity; for when the apparatus is hermetically confined in a given portion of air, the phenomena cease in process of time, in consequence of the want of oxygen.

5. Batteries can be constructed with one metal only.

(189.) Fifthly, that the Electromotive force arising from the contact of heterogeneous metals, is not indispensibly requisite for the production of Galvanic action, is proved by the success which has attended the attempts of Sir H. Davy, to form Galvanic batteries with one kind of metal only, and two dissimilar fluids, as already noticed, (sec. 114—116.) Galvanic combinations have, indeed, been formed without the presence of any metallic substance, (sec. 120;) and even when the battery was composed solely of animal substances, (sec. 121.)

Fluids may also exert an Electromotive action.

(190.) The only possible way of reconciling these facts with the theory of Electromotion, is to admit that fluids, as well as solids, are capable of exerting a degree of Electromotive action when applied to certain metals, or other solid substances. Let this principle be once established, and its operation must also be sensible in the ordinary forms of Galvanic combinations. If it be admitted that some portion of the effect of the Voltaic pile may be ascribed to such a power; we may next inquire whether it may not be sufficient to produce the greater part, nay even the whole of the effect?

Researches of Becquerel on this subject.

(191.) In order to investigate the precise influence of the fluids interposed between the plates of the Voltaic instrument, in the production of the Electrical phenomena, Mr. Becquerel has lately instituted a series of interesting and highly important experiments. His first object was to ascertain what are the Electrical states induced, when an acid or alkaline solution is placed between two dissimilar metals. For this purpose a copper capsule, filled with either an acid or alkaline solution, was placed on the copper plate of the condenser; the solution was then touched with a plate of zinc, but so as not to come in contact with the copper; the lower plate of the condenser was next touched with the finger; and after a lapse of twenty seconds, the upper plate was removed. The electrometer attached to the condenser immediately indicated that the copper capsule had received positive Electricity. The experiment was reversed by using a capsule of zinc filled with either solution; and the lower plate of the condenser was touched with a plate of zinc, to destroy the Electromotive action between the capsule and the plate; and a plate of copper, held between the fingers, was immersed in the solution. On raising the upper conducting plate, the electrometer showed that the zinc capsule had become negative.[*]

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(192.) It is proved, then, by these two experiments, that when zinc and copper are separated by an acid, or an alkaline solution, and are not otherwise in contact, the copper becomes positive, and the zinc negative. This result shows that the important law assigned by Volta to the action of the metals, (sec. 173,) namely, that when a pile is formed entirely of metals, the Electrical conditions of the two extreme metals is the same as if they were in direct contact, is not applicable to the case in which an acid or alkaline liquid is interposed between the two metals; for, according to this law, the zinc should be positive, and the copper negative, which is just the contrary of the result actually obtained.

(193.) Mr. Becquerel also examined what takes place on the contact of a metal with a saline solution; of copper, for instance, with a solution of muriate of soda; and found that, in these circumstances, the copper became negative, and the solution positive.

(194.) If we still consider these several Electrical changes effected by the action of the fluids on the respective metals with which they are in contact, as the results of an Electromotive force; then it will be obvious that such a force will entirely cooperate with the supposed Electromotive force arising from the mutual contact of the metals, in producing a circuit of Electricity in the very direction in which we observe it to take place in the Voltaic battery, (sec. 4.)

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(195.) But an obvious distinction will here suggest itself, between the Electrical changes resulting from mere contact, as in the case of the heterogeneous metals, and those which accompany the contact of a metal with a fluid, exerting a chemical action upon it. If the dry crystals of an acid be brought into contact with a plate of metal, and then separated, the metal is always rendered positive, and the acid negative.[†] In this case, no chemical combination has taken place. But if the acid, instead of being in a dry crystalline form, be in a liquid state, and capable of acting chemically on the metal, such as oxidating it, and dissolving the oxide so formed, the Electrical result, as we have just seen, will be exactly the reverse of the former, the acid will have become positive, and the metal negative. If the liquid in the Voltaic battery, therefore, assist in propelling the Electricities in the direction conformable to these latter results, as is really the case; is not this a proof that it does so in consequence of its chemical action, and not from any force derivable, like that of the metals, from mere the action of chemical affinities, of which Electricity may be one of the concomitant effects.* But Dr. Wollaston was the first who decidedly pronounced that the oxidation of the metal in the pile is the primary cause of its Electrical effects. This he thinks may be inferred from the following experiments, which exhibit the Galvanic process reduced to its most simple state.

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[*] *Traité de Physique*, ii. 531.

[†] Ibid. 532—535.

[*] *Annales de Chimie*, tom. xxvi

[†] Davy, *Elements of Chemical Philosophy*, p. 59.

Experiments in support of the chemical theory.

1. If a piece of zinc and a piece of silver have each one extremity immersed in the same vessel, containing very diluted sulphuric or muriatic acids, the zinc is dissolved and yields hydrogen gas, by the decomposition of the water of the acid solution: the silver, not being acted upon, has no power of decomposing water; but, whenever the zinc and silver are made to touch, or any metallic communication is made between them, hydrogen gas is also formed at the surface of the silver. Any other metal besides zinc, which by assistance of the acid employed is capable of decomposing water, will succeed equally, if the other wire consist of a metal on which the acid has no effect.

2. If zinc, iron, or copper, are employed with gold, in dilute nitric acid, nitrous gas is formed, in the same manner, and under the same circumstances, as the hydrogen gas in the former experiment.

3. Experiments analogous to the former, and equally simple, may also be made with many metallic solutions. If, for instance, the solution contain copper, it will be precipitated by a piece of iron, and appear on its surface. Upon silver, merely immersed in the same solution, no such effect is produced; but as soon as the two metals are brought into contact, the silver receives a coating of copper. In this case, Dr. Wollaston adds, we have no reason to suppose that the contact of the silver imparts any new power; but merely that it serves as a conductor of Electricity, and thereby occasions the formation of hydrogen gas.†

Theories combining both principles,

Attempts have often been made to reconcile these two theories, by supposing that the causes assigned both by the one and by the other, are jointly in operation, and concur in producing the observed phenomena. Sir H. Davy conceived that the Electricity evolved by the mutual contact of the metals, might be the first step in the series of Electrical changes; and that the effect, so begun, was continued and increased by the chemical actions taking place between the oxidable metal and the fluid, which tended to restore the equilibrium of Electricity between the adjacent plates of successive pairs. He also thought that the law of induction was in operation among the different strata of the pile, and contributed to increase the intense Electrical state of each, in every successive alternation of the ternary elements. Induction, it is well known, takes place only when the transmission of Electricity is prevented by the interposition of a non-conducting medium; and the liquid portion of the pile, having but imperfect conducting powers, might thus, as Sir H. Davy supposed, give occasion, in Electricities of such low intensity, to a degree of Electrical induction. Thus every copper plate being itself negative, produces by induction an increase of positive Electricity upon the opposite zinc plate; and every zinc plate, an increase of negative Electricity on the opposite copper plate; the intensity increasing with the number, and the quantity with the extent of the series.* It has been objected to this explanation of the action of the pile, that the effects of induction are most conspicuous when the interposed substance has the least conducting power; while in the Voltaic pile, on the contrary, the greater the conducting power of the fluid, the more powerful are its effects. Comparative insulation of the parts of the pile, even by liquids, is by no means an essential requisite for the action of the instrument. Some curious experiments on this subject have been made by Mr. Singer, which it would take too much space to detail, but to which we beg leave to refer our readers.† Mr. Children, by applying to his large battery an arrangement which reduced the whole to a single pair of plates of zinc and copper, each presenting a surface of 1344 square feet, found that when they were suspended quite out of contact with any liquid, they produced no sensible effect on a connecting wire of platina, the 5000th of an inch in diameter; although the same wire would have been instantly ignited by a single pair of such plates, one inch square, immersed in a diluted acid. The ratio of the areas of the plates in the two experiments was as 1 to 48384; yet no traces of Electricity by induction were discovered.

And assuming the operation of induction.

(203.) A variety of theoretical views have been entertained by different philosophers on the subject of the excitation of Galvanic Electricity, and on the mode in which it is transmitted along the series of alternations composing the battery, and accumulated at its poles. But it would far exceed the limits within which we must confine ourselves, to enter into so extensive a field of speculation, or even to attempt giving such an outline of these theories as could be rendered intelligible in so small a space. It must be admitted, indeed, that notwithstanding the laborious researches of so many experimentalists in this department of science, many important questions with respect to the origin of Galvanic power, still remain unresolved.

3. *Theory of the Chemical effects of Galvanism.*

(204.) Having discussed the principal theories that relate to the origin of Galvanic power, there still remains another branch of inquiry; namely, into the mode in which the different phenomena, we have described as the effects of that power, are produced.

(205.) The operation of the Electric currents, set in motion by the Voltaic apparatus, in the ignition of metallic conductors, and in producing various physiological effects by their passage through animal bodies, is in general sufficiently intelligible from its analogy with corresponding effects produced by ordinary Electricity. The same observation applies also to the Electro-Magnetic results which are obtained by Voltaic Electricity. The theories of all these phenomena have no particular relation with Galvanism, but are comprehended in the general theory of Electricity, which we have elsewhere considered.

(206.) We ought, perhaps, to except from this generalization, the phenomena of chemical decomposition, produced in the fluids that are interposed in the circuit of communication between the two poles of the Voltaic battery, and which almost exclusively appertain to the science of Galvanism. It is a subject, besides, involving peculiar difficulties, and respecting which there still prevails much obscurity. We shall first give a statement of these difficulties, and then take a view of the theories which have been proposed for their solution.

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* *Journal de Physique*, xlix. 348.

† *Philosophical Transactions for* 1801.

* *Philosophical Transactions for* 1807, p. 45; and *Elements of Chemical Philosophy*, 166.

† Singer's *Elements*, p. 433, *et seq.*

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(207.) Let us, in order to simplify the inquiry, first consider the phenomena presented by the decomposition of water in the interrupted circuit of the Voltaic battery. It is found that when the battery is powerful, the two wires which form the communication with the poles, may be situated at a considerable distance from each other, and even placed in separate vessels, provided the portions of water in which they terminate, are made to communicate with one another by means of a syphon full of water, or even by moistened threads. It is evident that the Electricity, of which the wires are the conductors, must here pass through a considerable circuit of water, in its course between the extremities of the wires; and yet, under these circumstances, we find that the whole of the oxygen of the water which is decomposed is collected at the positive wire, while the hydrogen is found at the negative wire. How, it may be asked, is this transfer of the respective elements of the water effected; and in what part of the circuit does the decomposition take place? If we suppose the particle of water in contact with the positive wire to be the one that gives out its oxygen by the influence of the positive Electricity, why is not its other element, the hydrogen, also extricated at the same point; and what has become of it? We observe, indeed, that a bubble of hydrogen has been given out at the negative wire. Is this the identical particle, the disappearance of which at the positive wire we were at a loss to account for? But if it be, how can it have travelled unseen, and undetected by any indication of its rapid movement, through so great an intervening space? The velocity requisite for such a transfer would be exceedingly great, as appears from the following experiment which was made in the year 1807, by the Writer of this Paper, in conjunction with Mr. Sylvester. The ends of two platina wires, communicating with the poles of a powerful battery, were introduced into two separate vessels of water, which were made to communicate by a tube, bent in the form of a syphon, and filled with a solution of muriate of soda. The whole length of the circuit of fluid between the two wires was forty-six inches. Microscopes were applied to the ends of the wires, for the purpose of enabling the two observers to ascertain the precise moment when the gases made their appearance at the respective wires. No sensible interval of time could be perceived between the appearance of the oxygen gas at the positive, and of the hydrogen gas at the negative wire, when the communications with the battery were established.

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(208.) The transfer of material and ponderable substances, such as those which constitute the elements of water, with even a moderate velocity, might be expected to produce visible currents in the fluid through which they passed; for their motion, whatever be the moving force which produced it, must be accompanied by a certain momentum, and must displace the particles of the fluid through which they pass, and which oppose their passage. But no indication of any current or displacement of the fluid can be detected. When the fluid contains globules of dust, which by their movements would point out such currents if they existed, all appears tranquil and unchanged, even when subjected to minute inspection in the field of a microscope. Mr. Wilkinson on applying a magnifying power of about 300,000 times with a solar microscope, could not detect any current.* Professor A. de la Rive, of Geneva, made the same observation by employing a microscope of Amici.† It is evident that if, instead of assuming the decomposition to take place in the particles of water in immediate contact with the positive wire, it were supposed to take place in any other part of the line of circuit, the same difficulty would occur in explaining the transfer of one or other, or of both the elements.

Hence the composition of water was doubted.

(209.) So great has been the difficulty of explaining these phenomena of transfer, that in the opinion of some chemists it has been deemed entirely subversive of the doctrine of the composition of water. Conformably with this view, water was considered as a simple substance, constituting the ponderable bases both of oxygen and of hydrogen gases; the former being composed of water united to positive Electricity, the latter, of water combined with negative Electricity. This theory was first advanced by Professor Ritter of Jena, and was embraced by several other philosophers; it was again brought forward by Dr. Gibbes, of Bath, in a Paper which was read to the Royal Society, but not published.

Theory of Monge and Fourcroy.

(210.) Another solution of the difficulty was attempted by Monge, on the supposition that when one of the elements of water is liberated by the influence of Electricity, the other combines with the adjoining particles of water, forming water with excess, either of hydrogen or of oxygen; these new compounds are supposed to pass in a continued stream to the opposite wires, where they again part with the superabundant ingredient, which appears in its natural form. This hypothesis was maintained in a detailed memoir by Fourcroy.‡

Dr. Bostock's theory.

(211.) Dr. Bostock has proposed an hypothesis which is remarkable for its ingenuity, and its accordance with a variety of facts relating to this subject. He supposes that a strong attraction exists between Electricity and hydrogen. The Electricity which passes from the positive wire into the water, and decomposes it, whereby its oxygen is liberated, unites with the hydrogen, and carries it invisibly to the negative wire; the superior attraction of which for Electricity, again occasions the separation of the hydrogen, and its appearance in the gaseous state.§ But this theory would require, as we shall presently see, to be greatly modified in order to reconcile it with more complicated cases of transfer.

Dr. Roget's explanation.

(212.) In a Paper which was read to the Manchester Philosophical Society in 1807, but not published, Dr. Roget suggested the following mode of explaining the phenomena. "Instead of supposing Electricity to have an affinity for hydrogen, let us suppose it repulsive of that element. We may conceive the agency of Electricity to extend throughout the whole of the fluid line connecting the two wires. The hydrogen existing in every particle of the water in this line, will have a tendency to move from the negative towards the positive wire. These particles of hydrogen may be considered abstractedly as forming a row of particles; while those of oxygen compose another row. While the particles in the former row are moving together, by the agency of the Electricity, in a direction towards the negative wire, all those which have not yet reached it, will merely have to pass in succession from one particle of oxygen to the next, among those in the latter row. They will not appear in the form of gas, because the instant each particle has quitted the particle of oxygen with which it was associated, it finds another to combine with; and this process will continue, till it has arrived at the end of the line, when finding no oxygen to unite itself with, it will make its appearance in the form of a bubble of gas. In like manner, the first particle of hydrogen in the series, by its abandoning the first particle of oxygen, which finds no other particle of hydrogen to replace it, occasions the oxygen to appear at that point in the form of gas. We have thus the two gases formed at each end, not from the same individual particle of water, but from the two which happen at that moment to be in contact with the wires. The production of the two gases will take place at the same instant in both places; each particle having only to move one step, that is, from one particle to the adjoining one, instead of having to traverse the whole extent of the line: and no current will be perceptible in the fluid. The current of hydrogen which sets in one direction, will necessarily be accompanied by a corresponding current of oxygen in the contrary direction. If this theory be correct, the operation of gravity in favouring the descending current of the heavier element, namely, oxygen, might be rendered sensible; and that this is actually the case, is confirmed by an observation of Mr. Sylvester, who found that when the wire which gives out oxygen is placed below that which gives out hydrogen, the effect is sensibly greater, than when the positions are reversed." A similar view of the subject has been taken by Dr. Henry,* and by Grotthus.†

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* *Elements of Galvanism*, ii. 386.

† *Annales de Chimie et de Physique pour* 1825.

‡ See Report made to the French National Institute by Cuvier.

§ Nicholson's *Journal*, iii. 9. See also Thomson's *Annals of Philosophy*, iii. 85.

Motions exhibited by mercury

(213.) That visible motions are sometimes produced in fluid conductors when transmitting the Electric current, has been shown by Sir H. Davy; who noticed very singular convulsive agitations into which mercury is thrown, when placed within the circuit of a powerful Voltaic battery discharged through water.‡ These motions, which frequently are of a violent and capricious kind, have attracted, more particularly the attention of Mr. Herschel, who has made them the subject of an interesting research, of which he has lately given an account in a Paper read to the Royal Society.§

(214.) But none of the theories we have been considering are adequate to explain the phenomena of the transfer of the elements of saline bodies, of which we have already given an account, (sec. 56—60.) They more especially fail when applied to the cases in which these elements are made to traverse other fluids, (sec. 61.)

(215.) Some interesting researches on this subject have lately been made by Professor A. de la Rive.* By dividing the interior of a vessel into three compartments, by means of partitions of bladder, which prevented the mixture of the liquids contained in each compartment, but did not intercept the passage of the Electric currents, he ascertained from the changes of colour in blue vegetable tests added to a solution of muriate of soda, with which all the compartments were filled, that the decomposition of the salt took place only in those parts which were in immediate contact with the metallic wires. However long the experiment was continued, no alteration of colour took place in the liquid occupying the middle compartment. Hence he infers, that the whole mass of the solution does not, as was supposed, divide itself into two portions, the one positive and the other negative.

(216.) Mr. Porret had already observed, that if a vessel be divided by a membranous partition into two compartments, of which the one was filled with water, and the other contained but a very small quantity; and if the positive wire be inserted in the former, and the negative wire in the latter, the water will be impelled from the first compartment into the second, through the partition; and will at length rise to a higher level in the latter than in the former.† M. de la Rive, upon repeating these experiments, found that this result is obtained only when distilled, or river water, which has but a small conducting power, is used; but if a sufficiently concentrated saline solution is employed, no effect of impulsion is perceptible. On varying the experiments by employing a greater number of compartments, to which tubes were respectively joined, so as to indicate, by the height at which the fluids stood in them, the changes of volume taking place in each particular portion of the solution, he deduced the conclusion that their decomposition was effected only in those parts that were in immediate contact with the metallic surfaces, which communicated and received the Electricities, that is at the positive and negative poles. This result was also confirmed by placing at the same time several different solutions in the circuit. If, for instance, a solution of muriate of ammonia occupy the two extreme compartments, while the intermediate one is filled with solution of sulphate of zinc, the elements of the former alone will be developed at the respective poles; on the other hand the elements of the sulphate of zinc, will make their appearance separately, when this order is reversed, by placing this solution in the extreme compartments, and that of muriate of ammonia in the middle one.

(217.) The experiments in which totally different saline solutions are placed at the two ends of the circuit, and in which it is found that the two acids are accumulated at the positive, and the two bases at the negative wire, prove that there is an actual transfer of these elements through the whole line of circuit. It appears, then, that the two Electric currents which traverse the fluid, decompose the first particles with which they meet, and carry along with them, respectively, the particular elements for which they have an affinity, and again deposit these elements on arriving at the metallic surface, which they enter in proceeding on their course towards the pole of the battery to which they are tending.

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* *Manchester Memoirs*, New Series, ii. 293; and Nicholson's *Journal*, xxx. 270.

† *Annales de Chimie*, lviii. 54.

‡ *Elements of Chemical Philosophy*.

§ *Philosophical Transactions for* 1824, p. 162.

* *Annals de Chimie et de Physique*, 1825.

† Thomson's *Annals of Philosophy*, viii. 74.

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(218.) Thus, in explaining on this hypothesis the Galvanic decomposition of water, it may be assumed that the Electric current which issues from the positive pole, seizes upon the particle of hydrogen belonging to the contiguous particle of water, and carries it on till it reaches the negative pole, where, meeting with a solid conductor, which is impervious to the hydrogen, the Electricity abandons it on entering into the metal. The current of negative Electricity acts in the same way upon the oxygen, and effects its transfer from the negative to the positive pole. The same processes are effected with regard to the acids and bases of salts; and when one element is carried by the Electric current through a fluid for which it has an affinity, the result will depend on the balance of affinities; if that which it has for Electricity should prevail, it continues its course in conjunction with it; but if its affinity for the element of the liquid happen to predominate, it quits the Electricity and remains behind. We find the latter case occur whenever an insoluble compound is the result of such an affinity, as in the examples given in sec. 63.

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(219.) M. de la Rive ascertained by the application of a very delicate galvanometer, that Electric currents were established in the fluid between the two wires; and that they occupied a considerable extent in the fluid, and were most intense in the direct line joining the two poles, and especially in the vicinity of those poles. The extent of diffusion of these currents was uniformly in proportion as the fluid was a more imperfect conductor of Electricity; so that it would appear that each current, on emanating from its respective pole, and meeting with a substance which opposed an obstacle to its free passage, was obliged to deviate from the rectilineal course, in order to describe a curve in passing to the opposite pole. The experiments of Mr. Herschel above referred to tend to throw great light on this curious subject.

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(220.) This diffusion of the currents throughout the whole liquid was rendered still more manifest, by separating the vessel which contained it into two compartments, by a lamina of platina. Although the plate of metal was situated perpendicularly to the line joining the two wires, and was nearly an inch in diameter; and although each of the wires was at a distance of only three inches from the plate, yet there appeared on each of its sides, and over its whole surface, a very considerable disengagement of gas; and the saline solution, which was coloured blue, received a red and green tinge, in every part which was contiguous to the surface of the plate. By interposing a greater number of plates, the decompositions were effected in much greater quantity; for they took place at each of the surfaces through which the Electric currents were thus made to pass. The effect was much diminished, as indeed might be expected, if the different portions of fluid were allowed to communicate round the edges of the metallic partitions; as a considerable part of the Electric currents found their way by this circuitous route, which they seemed to take in preference to the more direct passage through the plates. From a number of experiments in which M. de la Rive succeeded in forming a comparative estimate of the intensities of the currents under different circumstances, by means of a magnetic galvanometer, he ascertained, that the intensity of the Electric current is impaired according to the number of metallic plates which are interposed in its passage. The diminution of intensity is next to nothing when the current is very energetic, and proceeds from a pile composed of a great number of plates; but it becomes more and more sensible, according as the original intensity of the current is less considerable. When, in two comparative experiments, in which the current had passed through an unequal number of plates, the intensity has been rendered equal, that current which had previously passed through the greater number of plates, will pass through every succeeding plate with less diminution of intensity than the other. When different metals were used in these experiments, it was found that the more readily the metal was acted upon by the liquid conductors, the less was the diminution of intensity produced by the passage of the Electric currents through them.

Explanation of the effects attending an increase of the number of the plates.

(221.) By the aid of the conclusions deduced from these interesting researches, M. de la Rive is enabled to account, in a very satisfactory manner, for the differences of effect, particularly in regard to chemical decomposition which accompany the multiplication of pieces in the Voltaic pile. The Electric current is disposed to pass with greater readiness through imperfect conductors, which present a degree of resistance when it has previously traversed a great number of metallic plates. The phenomena correspond with those which would take place, if we could imagine that there were two distinct portions of Electric currents, the one capable of passing indiscriminately through all sorts of conductors, good or bad; the other capable of passing through good conductors alone. The passage of the currents through a great number of plates effects a separation of these two portions, the plates retaining that which cannot pass through bad conductors, and giving passage to the other portion alone. The Electricity elicited by a pile consisting of a small number of plates, not having been thus *filtered*, (if the expression may be allowed,) only a part of it will pass through an imperfect conductor which is presented to it, and the other part will be arrested; but if a good conductor be presented to it, the whole of the Electricity finds a ready passage; and the effects it will produce will be much greater. Electricity of the former kind will only be capable of producing chemical decompositions, and of passing through organized bodies; but, in the latter case, it is adequate to the production of all the calorific and Magnetic effects. These important modifications in the action of Electric currents, obtained by different means, suggest a remarkable analogy with the modifications of Light and of Heat, under circumstances somewhat parallel.

PART V.

HISTORY OF GALVANISM.

Galvanism.

(222.) The full account which we have given of the principal facts belonging to the science of Galvanism, and of the most plausible theories devised for their explanation, may be regarded as comprising an exposition of the present state of our knowledge in this department of Physics, and will supersede the necessity of our entering into any copious historical details as to the researches and opinions of its early cultivators. Little interest can attach to speculations in which truth is so much involved in error as to be with difficulty recognised; or to laborious investigations, undertaken with a view of ascertaining facts which we have since been able to arrive at by a much shorter process. Still less need we dwell upon abortive attempts to establish theories, which our more enlarged acquaintance with the subject enables us easily to refute. Much instruction, it is true, may often be reaped from a revision of the steps by which important principles were deduced; but for this purpose it would be necessary to enter into a minuteness of detail incompatible with the objects, and far exceeding the limits of this Treatise. We must content ourselves, therefore, with presenting a very brief outline of the History of Galvanism.*

Origin of the science.

(223.) This science owes its origin to an accidental observation made in the year 1791, in the laboratory of Galvani, Professor of Anatomy at Bologna. His wife, being in a declining state of health, employed as a restorative a soup made of frogs. Several of these animals deprived of their skin happened to be lying on a table, near an Electrical machine. While the machine was in action, one of Galvani's pupils happened to touch, with the point of a scalpel, the crural nerve of one of the frogs that was nearest to the prime conductor; when it was observed, that upon each contact, the muscles of the limb were thrown into strong convulsions. This curious fact attracted the notice of the Professor's lady, who communicated it to her husband. He repeated the experiment, and varied it in different ways; he then perceived that the convulsions took place only at the time that a spark was drawn from the prime conductor, while the nerve of the frog was, at the same moment, touched by a substance which was a good conductor of Electricity.

Fact observed by Galvani.

But previously known to Du Verney.

(224.) It is a curious circumstance, that about a century before, the very same observation had been made by Du Verney,† without its having attracted from philosophers the attention it deserved; and when it occurred to Galvani, it might, perhaps, have shared the same fate, had it not been that this philosopher happened to be at that time engaged in an investigation into the theory of muscular motion, which he conceived was owing to Electricity. This newly observed fact, appearing to confirm his hypothesis in a very remarkable manner, inspired him with new ardour for prosecuting the inquiry. He found that contractions could be excited in the limbs of frogs by the Electricity of the atmosphere; and in the course of his investigations on his subject, he was led to the discovery that an effect of the same kind was produced, independently of the Electricity of surrounding bodies, merely by establishing a communication by means of metals between the nerves and muscles. He drew from his experiments the general conclusion that these different animal parts possessed an inherent Electricity, forming an apparatus analogous to the Leyden jar, which might be discharged by the application of proper conductors.

(225.) Soon after the publication of Galvani's work,* in which these discoveries are detailed, there appeared some letters of Valli† on the same subject; and in the year 1793, Dr. Fowler published his *Essay on Animal Electricity*, in which he discusses with great ability the question whether the phenomena of Galvanism are referable to Electricity; and is led, in consequence of the imperfect state of the science at the time he wrote, to form the opinion that they are the results of distinct agents. He made a great number of observations on the effects of Galvanism in different animals, and on different parts of animals. He repeated the experiments of Sulzer, already noticed, (sec. 85;) and the same subject was further prosecuted by Professor Robison.

(226.) Professor Volta, of Pavia, in a letter to Cavallo, published in the *Philosophical Transactions for* 1793, entered into a train of highly original observations and experiments. He successfully refuted Galvani's hypothesis concerning the analogy of the animal body to the Leyden jar; and laid the first foundations of that theory, which has since found so many advocates; namely, that the phenomena arise from the developement of small quantities of Electricity by the mutual contact of two different metals, and that the animal organs are affected in consequence of their being highly susceptible of this Electrical influence.

(227.) Dr. Wells's Paper on this subject, in the *Philosophical Transactions for* 1795, is deserving of notice, as establishing his claim to the discovery of the fact, that charcoal may be employed, together with one of the metals, in exciting the Galvanic influence; and that it is also a conductor of that influence. Dr. Wells arrives at the correct conclusion, that Galvanism is identical with Electricity; from the consideration that the same bodies are equally conductors of both. It is singular that Humboldt, who engaged about the same period in a very extensive series of investigations on the irritability of the muscular fibre, as a test of which he employed the Galvanic power, should have adopted an opinion opposite to that of Dr. Wells on this subject, and as we now know, contrary to the truth. He may, however, be considered as the discoverer of the very important fact, that contractions may be excited in the muscles of an animal, by placing them simply in contact with the nerves in certain situations; a fact which was afterwards pointed out more fully by Aldini; (sec. 121.)

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* The best work on this subject is that of Dr. Bostock, published in 1818, and entitled *An Account of the History and Present State of Galvanism.* It is executed with great accuracy and ability, and we have been much indebted to it in drawing up the following summary.

† *Histoire de l'Académie Royale des Sciences pour* 1700, p. 40.

* *De Viribus Electricitatis in Motu Musculari Commentarius.*

† *Journal de Physique*, tom. xli. and xlii.

(228.) An elaborate Memoir on the subject of animal Electricity was drawn up by a Committee of the French Institute, composed of Morveau, Fourcroy, Vauquelin, Hallé, Coulomb, Sabatier, Pelletan, and Charles. It contains an examination of all the early opinions that had been advanced concerning Galvanism, and details a great variety of original experiments. The authors of the Memoir distinguish in the circuit of parts essential to the experiment, the parts of the animal, which they denominate the *animal arc*, and the other portion, which they term the *excitatory arc*, and inquire into the various changes of effect consequent upon variations in the forms and circumstances of these two portions.

(229.) The paper of Fabroni, to which reference has already been made in sec. 202, appeared in the year 1799; and although full of original views, did not, at the time, excite much attention.

(230.) The discovery of the Galvanic pile, which forms so important an era in the history of the science, was made by Volta in 1800, and was the fortunate result of the theory he had formed respecting the source of the evolution of Electricity by the contact of metals. He conceived that by increasing the number of plates with a liquid conductor between each pair, the Electricity would be much increased; and he found, upon constructing a pile upon this plan, that it produced more violent convulsions in the limbs of animals than any single pair of plates, and was even capable of giving shocks similar to those of the Leyden jar. His description of this instrument was given in the *Philosophical Transactions for* 1800: and its properties and powers were immediately the subject of investigation among all the philosophers of Europe. Messrs. Nicholson and Carlisle were the first who engaged in this inquiry; and their labours were speedily rewarded by the discovery of the decomposition of water by its means, (sec. 52,) and the detection of the qualities of the Electricities evolved at each of its poles, (sec. 17.) These important discoveries were confirmed and extended by Mr. Cruickshank, of Woolwich, who instead of the original pile of Volta, substituted the trough apparatus which bears his name, (sec. 8.) Several new experiments on the operation of the pile, were also made about the same time by Colonel Haldane.[*] He found that the apparatus ceased to act when it was immersed in water, or placed in the vacuum of an air-pump; and that the presence of oxygen was essential to its action. Dr. Henry, of Manchester, was also among the first who employed the powers of Galvanism for the purposes of chemical analysis, and he decomposed by its means several of the acids, and also ammonia.

Davy,

(231.) But the most brilliant era in the history of this science, is that in which Sir H. Davy pursued the career of discovery which has furnished such splendid and important results. His success in obtaining the two elements of water separately from each other, from two different portions of that fluid; his invention of modes of forming Galvanic piles of one metal only, together with fluid conductors, and even of charcoal, instead of any metal; and his ascertaining that the effects of the pile are in proportion to the energy of oxidation, constituted the earlier steps of his progress in this career.

Wollaston,

Dr. Wollaston's researches on the subjects connected with Galvanism, though not numerous, bear the stamp of his characteristic sagacity and penetration; and have thrown considerable light on the theory of that science. The differences in the modifications of Electric power when derived from the common machine, and from the Voltaic battery, were first pointed out by Nicholson; but were confirmed and illustrated by Dr. Wollaston, who gave greater precision to our ideas on the theory of its production, and succeeded in imitating the chemical action of Galvanism by the agency of common Electricity, (sec. 77.)

Trommsdorff,

(232.) The next step in the progress of our knowledge of the effects of the Voltaic apparatus, was the discovery of Trommsdorff, as to the efficacy of large plates in producing combustion of thin metallic leaves, (sec. 25.)

French Chemists,

Experiments on the combustion of metals were performed about the same time by Fourcroy, Vauquelin, and Thenard.[*] The comparison between the effects of Electricity and Galvanism was further pursued by Van Marum, in conjunction with Professor Pfaff, of Keil, in which they employed the great Teylerian machine at Haarlem.

VanMarum and Pfaff,

(233.) The labours of subsequent experimentalists were chiefly directed to the establishment of various points which had previously been subjects of doubt and controversy; to the improvement of the apparatus, and to discussions concerning the nature of Galvanic action, and its relation to chemical affinity. They have furnished materials for a great number of memoirs contained in a variety of scientific journals, of which it would be impossible to attempt a review, or even an enumeration in this place. During this period, the attention of philosophers was again drawn to the effects of Galvanism upon the animal body, and various experiments, already referred to, (sec. 95, 96,) were made in 1803, by Aldini, Professor of Natural Philosophy at Bologna, and nephew of Galvani, and were repeated by other naturalists in different countries in Europe. Attempts were also made to introduce the employment of Galvanism in medicine, especially in those diseases for which common Electricity had been found useful; but the expectations of advantage from its application have been very generally disappointed, and it had again fallen into disuse as a medical agent, until its recent employment by Dr. Philip, (sec. 102.)

Aldini,

Hisinger and Berzelius,

(234.) The most important step that was made at this time in the theory of Galvanic action, resulted from the labours of Hisinger and Berzelius, an account of

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[*] Nicholson's *Journal*, 4to, iv. 241, 313.

[*] *Annales de Chimie*, xxxix. 103.

Davy,

De Luc,

which was published in the first volume of Gehlen's Journal, in 1803. They ascertained, by a numerous series of experiments, the transfer of the elements of water and of neutral salts to the respective poles of the battery. This law was verified and extended by Sir H. Davy in the masterly train of investigation, of which we have already given a detailed account, (sec. 55—70,) and which affords so beautiful and perfect a model of a truly philosophical inquiry. While Sir H. Davy was engaged in these researches, De Luc occupied himself with the analysis of the pile, and in examining the various cirumstances and conditions from which its power is derived. We have already given an account of the results of his labours, (sec. 132—138.) In the course of the inquiries to which he was led by these experiments, he invented the instrument called the Electric column, of which we have described the properties, (sec. 139.) A claim of priority of invention with regard to his instrument was made by Hachette, in favour of himself and Desormes, stating that they had formed a dry pile so long back as the year 1803. Two objections may be made to this claim; the first, that De Luc's pile had been published some time before that of Hachette; and the second, that the two instruments are not analogous, the latter being by no means entitled to the appellation of a dry pile, (sec. 146.)*

Batteries of Children,

Royal Institution,

Wollaston,

Hare,

(235.) Mr. Children, in 1809, formed a very large and powerful battery upon the principle of Volta's *Couronne de tasses*, (sec. 7,) which produced very considerable effects, and afforded instruction as to the ratio between the quantities and the intensities of the Electricities produced by instruments of this kind. A still more powerful battery was constructed by the same gentleman in 1813; and about the same time that at the Royal Institution was made, (sec. 14.) Dr. Wollaston's ingenious elementary battery, which forms a remarkable contrast with these gigantic instruments, was constructed by him in 1815. A still larger battery than any of the preceding was formed by Mr. Children in the same year. Dr. Hare's first form of the Calorimotor, so named from its extraordinary calorific power, was constructed in 1819;* his improved apparatus, described in sec. 12, was constructed in 1821: that of Mr. Pepys, made for the London Institution, in 1823.

(236.) Of late years the attention of the philosophic world has been in a great measure drawn away from the immediate consideration of the theory of Galvanism, by the study of those effects which establish its relation with the magnetic properties of iron, and which have constituted a distinct branch of the science, under the title of Electro-Magnetism. Yet the cultivation of this new science has not been without advantage to the progress of knowledge in respect to Galvanism, as it has furnished us with an admirable test of its agency in cases where its presence could not otherwise have been rendered sensible; see sec. 44. The invention of the Galvanometer derived from this principle, has conferred a signal benefit to the science, by affording the means of more extended investigations on the laws which govern its phenomena. It was by the acid of this instrument that De la Rive conducted those researches of which we have given an account. The inquiries of Sir H. Davy on the subject of Electro-Magnetism, have also, as we have already seen, (sec. 33—36,) led to the discovery of many curious circumstances with regard to the conducting powers of metals. The principal researches of importance, as far as respects the theory of Galvanism that have lately been undertaken, are those of Becquerel, on the Electricity evolved by the contact of metals with liquids, in which he availed himself of the Electro-Magnetic galvanometer, as well as of the more ordinary form of the condensing electroscope; an instrument which he considerably improved. These researches throw considerable light on the origin of the Electrical power in the Voltaic apparatus.

(237.) But by far the most important application of this science, is that which Sir H. Davy has lately made of it for preventing the corrosion of the copper sheathing of ships by sea water. An account of this admirable invention was read before the Royal Society in January, 1824; and published in the *Philosophical Transactions* for the same year.

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* See *Journal of Science*, ii. 161, 449.

* Thomson's *Annals of Philosophy*, xiv. 176.

GALVANISM.

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HEAT.

INTRODUCTION.

It might prove an amusing, and in some degree possibly an instructive task, were we to prefix to this Article a review of the opinions of ancient philosophers, and even of those in times comparatively modern, who have bent their genius to inquiries upon Heat; but reasons, which to us appear sufficiently cogent, have compelled us to abandon such an undertaking. The writings of the ancients on this and every physical subject abound in speculations neither founded upon, nor confirmed by, experiment; and if, passing over a long interval of time, we wish to learn what the extent of knowledge on this subject may have been at a period from which the steady advance of physical science may be dated, we have but to turn to the *Novum Organum* of Bacon for a very complete Treatise upon Heat. Complete we term it, with reference to the knowledge of that day; for as no one ever brought greater mental powers to bear upon the question, and none had before him possessed equally just views of the mode in which these powers might be most advantageously directed; and as he himself has selected his *Inquisitio de forma Calidi*, "*exempli gratia*," we feel that we can have done the philosophical world of that day no injustice by our selection. The limits, however, within which an Article of this sort must be confined, compel us to pass by historical disquisitions in general, in order that we may give as full and clear an account as possible of those researches which are to be treasured up in our minds, and constitute the present *knowledge* on this subject. We do this the more willingly, from a conviction that such a history is a matter of curiosity, rather than of utility.

For the sake of precision, it may be advisable that we say something in explanation of the terms employed in this Article. Heat is a vague and general word referring to our bodily sensations, and in that sense universally understood; but what is the cause existent in matter which produces those sensations upon the organization of our frame? For convenience in language, this cause, producing the sensation or effect of heat, has been termed Caloric. But if, again, it be asked what is Caloric? we confess ourselves unable to afford a satisfactory answer. Suppositions and theories are not wanting; but certainty has not yet been attained. By some, Caloric is thought to be a fluid; existent and material, though of such tenuity and imponderability, as to escape our observation as such, and to become manifest to us only by its effects upon our sensations, and upon all the ponderable forms of matter. By another party it is supposed that Caloric is not material, but is a property or principle of motion, which, by exciting a certain species of vibration among the particles of bodies, causes the sensation and effects of Heat. These difficulties will suggest to our readers the analogous case of the questionable existence of an electric fluid. (See Electricity, Introduction.) The plan we purpose to pursue in this Article, will, we trust, set us free from any practical difficulty arising out of this theoretical uncertainty. We shall find it convenient to speak of *Caloric* as if it were a substance, though imperceptible and imponderable; of its addition to, and abstraction from, all other bodies: for this mode, even when made use of in calculation, need not imply the admission of any theory, if we remember that it is but employed for the purpose of illustration. The arguments by which these opposite theories are supported will be brought together for comparison in the last chapter.

The word Temperature will also frequently occur. Heat expresses vaguely an effect or operation of Caloric. To *Temperature* we assign a more definite meaning; considering it the comparative measure of the effects of Caloric in bodies *referred to sensation*. Thus, if we feel one body to be hotter than another, we say that its temperature is *apparently* greater; and if we obtain any instrument for measuring the apparent temperatures of the two bodies, free from the fallacies to which our sensations are liable, we consider that we have the true ratio of the *temperature* of the bodies. It may seem an odd illustration, but we think it a familiar one, to compare temperature to the hand of a clock which tells us what the time is, according to that engine, but does not tell us over how many hours more the moving force will enable the clock to impel the hand; so temperature is an indication of a present external state of the body examined, which does not pretend to teach us the total Caloric existent in the body, nor even the quantity existing in a given portion of it.

It may be desirable that we should explain why the appearance of this Article will differ considerably from that form under which it has been usually presented by the scientific writers of this country. With them the doctrines of Heat have formed a part, and that not an inconsiderable one, in the systematic Treatises on Chemistry; and it is to those Treatises only that the English reader can at present apply for information on the doctrines of Caloric. Of these Treatises no country has produced better; but if we rightly estimate the limits due to physical and chemical science respectively, we cannot place the science which treats of Caloric as a mere appendage or preliminary step to the Treatise on Chemistry. We call it a branch of General Physics, and claim for it a rank corresponding to that of Electricity, Physical Optics, or Magnetism. The chemists have in this country been the able teachers of the doctrines of Heat; witness the Treatises of Thomson and Murray; but we are inclined to think that a separation of the two subjects will conduce to the clearer understanding of each. On this ground we have made Heat the subject of a separate Treatise; but as the connection with Chemistry is in some points most intimate, we have taken some care that by our line of demarcation the definitions including both sciences are not violated. To avoid repetition, we may here refer to the second division of our first chapter for the connecting links between these two subjects. For this division of the subjects we have the authority of many German and French writers; but for the arrangement, and for the proportion of consideration allotted to each part of our inquiry, we alone are responsible. By far the most complete general Treatise that has appeared abroad is in the elaborate work of M. Biot; it is however, perhaps, too mathematical for general readers, and by no means practical enough, nor general enough, for the purposes we had in view. But having said thus much, we are desirous of making ample acknowledgments to that admirable philosopher, for the service that his Treatise has been to us in the compilation of this Article. We term it a compilation, for we deem that it neither has, nor ought to have, any other title. The object of an Encyclopædia is not to propound new, and often doubtful discoveries, but to present a condensed summary of the present state of human knowledge in each department; with instructions and references for those who may choose to pursue the subjects more in detail. Under these views, the memoirs of the original experimentalists have been our primary guides; but we have also availed ourselves of the advice and opinions of our most able systematists. Wherever they were already sufficiently condensed, we have employed the words of an author in preference to our own. We have endeavoured to avoid all theory at present; not for the purpose of ultimately repressing such efforts of ingenuity, but for the purpose of adducing a systematic body of facts, upon the understanding of which, any one can alone be made competent to decide upon the validity of the hypotheses advanced.

The extent of this Article will not suprise any one acquainted with the subject, who shall consider the number of treatises usually separated, but which here form parts of one uniform whole. Chemistry is relieved from all that relates to the *integrant molecules* of bodies, and from every consideration which does not depend upon pure Chemical affinity.

All tables of general application and reference, are thrown together at the end of the Article in an Appendix. In the description of experiments, it might have produced a greater appearance of uniformity if we had reduced all the Thermometric indications to some one scale, as that of Fahrenheit or Celsius; but, on the other hand, the whole numbers frequently employed during those researches would have been altered to decimals or fractions, and a sort of evidence arising out of the ready comparability of their appearance would have been lost. Thus, in most cases, they are left in the original numbers of the writers.

It remains that we should present a tabular form or scheme of this Article: with regard to its execution, no one can be more sensible than the writer of it, how much more polished and complete his analysis might have been, had more time been afforded for the task. Punctuality, as far as attainable, is however essential in an undertaking like the present, and the time allotted for the completion of each article must depend upon the promised order of its appearance. In examining the memoirs, strict impartiality has been observed; for this, with the addition of our unworthy thanks, forms all the tribute we can pay to the labour and genius of those distinguished philosophers who composed them. And if the name or the praise of any one such, shall have been inadvertently omitted, it will be to us an additional cause of regret with regard to this Article,

> "*quod non*
> *Multa dies et multa litura coercuit, atque*
> *Præsectum decies non castigavit ad unguem.*"
>
> Hor.

SCHEME.

- **Chap.** I. *On the Effects of Heat.*
  - Div. I. *Physical* .... (affecting the integrant molecules of matter.)
    - § 1. Producing *Dilatation.*
    - § 2. „ *Fusion and Solidification.*
    - § 3. „ *Vapourisation.*
    - § 4. „ *Incandescence.*
  - Div. II. *Chemical* .... (affecting the constituent molecules of matter.)
    - Producing *Composition* and *Decomposition.* See **Chemistry.**

Chap. II. *On the Sources of Heat and Cold.*

Chap. III. *On the Radiation, Reflection, and Absorption of Heat.*

Chap. IV. *On the Conducting Powers of Bodies.*

Chap. V. *On the Specific Caloric of Bodies.*

Chap. VI. *Theoretical Opinions on the nature of Heat.*

Appendix. Tables.

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CHAPTER I.

ON THE EFFECTS OF HEAT.

Heat.

§ 1. *Dilatation of Bodies by Heat.*

GENERAL PRINCIPLES.

pansion.

(1.) It may be stated as a general fact, that all substances experience an enlargement of their volume, by an increase of temperature. The apparent exceptions to this law can scarcely be considered such as to destroy its generality, although they do present irregularities in its application, which it were highly injudicious to overlook. Such is the contraction of water by increments of temperature below 40° Fahrenheit. The expansion of some metals at the instant of congelation after fusion, is, apparently, connected with the tendency of their particles to arrange themselves in crystalline form; and the contraction of the clay balls in Wedgwood's pyrometer has been shown to depend upon an actual diminution in their substance, by the liberation of water which previously had existed in a state of intimate combination with the aluminous matter of which they are formed.

uality pan.

(2.) For a given change of temperature, different substances undergo different degrees of expansion. In solids, the quantitative expansion is not considerable; in liquids, it is greater; and in aeriform fluids it is much the greatest of all. A question may naturally here occur to the reader, whether in the same substance, be it metal, liquid, or gas, *equal* increments of temperature, *but at different temperatures*, produce equal expansive effects. It will be seen hereafter that this, though a fundamental inquiry, is one of the most perplexing ones which could have been advanced. The affirmative can only be answered of aeriform fluids. With regard to the solids and liquids, even if this property be found to belong to them, through some portion of the scale of temperature, it is fully proved, that their dilatations are highly unequal and irregular near to those fixed points of temperature at which they change their physical condition, and from solids become liquids, or from liquids pass on to the state of gaseous matter.

(3.) It has been usual to give a familiar exhibition of the dilatation of a solid from heat, by having an iron bar exactly fitting into a metal ring; the bar, on being made red hot, will no longer enter within the ring. The expansion of a liquid is seen in the bulb and stem of a thermometer; or should this illustration not be familiar, let fig. 1 represent a glass flask filled with cold water, linseed oil, or other liquid, at the ordinary temperature of the atmosphere. Let A be a point marked upon the neck at the surface of the liquid. On placing this flask over a lamp, or before a fire, the liquid will acquire an increase of temperature, and by its dilatation will rise above the point A. The same property in aerial fluids is also easily exhibited; let fig. 2 represent a common phial with a glass tube passing through the cork, or cemented into the neck of the phial so as to be air tight. The tube may reach to within one-fourth of an inch of the bottom of the phial, so as to dip below the surface of a little coloured liquor of any kind filling one-fourth of the bottle. Now hold this little instrument before the fire, or plunge it into hot water, the air that is in the phial will expand and force up the coloured liquor into the tube. This instrument, if graduated, is in fact an air thermometer. Fig. 3 represents one of more convenient form, but in principle the same.

g. 1. fig. 2

Chap. I.

Fig. 3.

The Thermometer.

Thermometer.

(4.) Could we but estimate the expansion of the iron bar in the first case, or the dilatation of the liquid in the second, or of the air in the third; and could we be satisfied that these various bodies underwent equal dilatations for equal accessions of temperature, we should then be in possession of instruments for measuring the temperatures of all bodies. Such in fact are our instruments, and such our means of experiment; but with certain cautions and corrections which it will be our duty to point out. Hence these instruments are called Thermometers.

(5.) By a careful admeasurement of the dimensions of bodies after they have been exposed to considerable changes of temperature, and suffered again to return to their original state, it is found that their volume is unaltered. But in the case of liquids, it requires some care, in order that they may sustain no actual loss by evaporation.

(6.) For very slight variations of temperature, air thermometers may with advantage be employed, from their great sensibility. Among fluids, alcohol and mercury are most commonly made use of; the former for estimating very low temperatures, at which mercury becomes frozen; but the latter is more rapid in its variations, and has its scale of temperature particularly well adapted to experiments lying between our ordinary atmospheric temperatures, and a heat about thrice as great as that of boiling water.

Construction of thermometer.

(7.) We are now in a condition to proceed to the construction of some instrument of this sort for the estimation of temperatures. For example sake, let us take the mercurial thermometer. Our first requisite is to obtain mercury in a state of uniform expansive power, and this is in some measure dependent on its purity; to fulfil this condition, the metal is first strained through leather, by which all dirt is removed; and then submitted to distillation, in order to obtain it pure, from small quantities of lead and other metals with which it is frequently adulterated in commerce, or found alloyed in its native state.

It would be by no means difficult, but might be rather tedious, to state all the precautions to be observed in making a good thermometer. We shall therefore content ourselves with mentioning some of the most material properties that such an instrument ought to possess; thus avoiding much of the practical manipulation, because we are convinced that it is much better for the experimentalist to purchase, if not the complete instrument, at least the tube ready filled, in order that he may carefully attend to its graduation. Under this impression it may be sufficient to state, that a thermometer tube, as represented in fig. 4, is made from a tube of thick glass of small but uniform capacity throughout, by closing one end, which is then heated and blown into a bulb by forcing in air from the mouth, or from a bottle of caoutchouc affixed to the other extremity. The mercury is introduced into the tube thus formed, first by heating the bulb over a lamp, for the expulsion of air; the open end is then dipped into pure mercury, and as the bulb cools the contraction of the air remaining within will allow the atmospheric pressure to drive up a quantity of mercury through the tube into the bulb. This operation is then repeated; but in the second heating, the bulb and tube may be filled with the vapour of mercury throughout, so that upon again dipping the extremity, the instrument may be almost, if not completely, filled. It is obvious, that as the volume of space in the tube is very small compared with the volume of the bulb, a small dilatation of the mercury in the bulb will be very apparent in the tube. The expansions of the fluid in the bulb are measured then by the elongations of the delicate column of mercury in the tube; and as the diameter of this column is supposed uniform, the length of the column serves for the measure of temperature. Hence the necessity of uniformity in the capacity of the tube; for if that condition be not fulfilled, a given quantity of mercury propelled from the ball by a given change of temperature, will not have the same apparent magnitude in the stem, and therefore if estimated by measure will produce an incorrect result. As this condition of perfect uniformity is not always attainable, it is sometimes desirable to make the graduations upon the scale of unequal length, in order to obviate this source of inaccuracy. After the thermometer tube has thus been filled, a certain quantity of the mercury is expelled by heat; the upper end of the stem is hermetically sealed, and, upon cooling, a vacuum is left in the upper part of the tube, by which the mercury meets with no obstruction in its dilatations from a body of air enclosed within the stem. Such obstruction would be, in fact, inconsiderable; but a still more cogent reason for this precaution is found in the great inconvenience frequently experienced from the separation of the mercury in the stem into small portions with the air intermingled, an evil that it is not always easy to remove. A thermometer may be examined as to this particular by placing the bulb uppermost; unless the bore of the tube be extremely minute, the mercury will immediately fall down so as to fill the stem quite to the bottom, if no air has been left in the tube.

g. 4.

eezing int.

(8.) It is found that a quantity of water, in which ice or snow is undergoing liquefaction, remains of one invariable temperature at all times; and that every accession of caloric to the water is employed in the fusion of more ice, so that the water can experience no rise of temperature as long as any particle of the ice remains. Hence one fixed point may be determined upon all thermometers by plunging them into such a bath, and marking this point upon the stem, or on the scale, as *melting point of ice.*

Boiling point.

(9.) Again, it is found that under a given pressure of the atmosphere, measured by the barometer, pure distilled water enters into ebullition at a temperature quite as invariable; some regard being had to the nature of the vessel in which it is placed, of which more hereafter. For if the heat communicated to the water be increased, no increase of temperature ensues; the only effect being that of driving off a greater quantity of steam in a given time. If then, the barometer standing at some altitude fixed upon by general consent, we place a number of thermometer tubes in boiling water, and mark the point to which the mercury rises in the stem of each, we have obtained another fixed point of temperature, well adapted for facilitating the comparison of observations made in distant countries by independent experimentalists, with instruments constructed by each upon these general principles.

In different thermometers it is obvious that the distances between these two points will be dissimilar, being in each case determined by the ratio existing between the volume of mercury in the bulb and the diameter of the tube.

(10.) In the present state of our question we are considering the temperature as measured by the dilatation of a volume of mercury, or other fluid, confined within a glass vessel. And to make this estimate with accuracy, it is obvious that all the mercury should be exposed to the action of the heated fluid; or, in other words, that the bulb should be quite immersed, and also that part of the stem which contains mercury. In obtaining the freezing point for the graduation of the instrument this is not difficult, because any portion of the stem may be immersed in the mixture of ice and water; but in ascertaining the boiling point of water, the difficulty seems greater, with an additional one superadded. For let us suppose the barometer at the proper height for this operation; it is true we may plunge the tube of the thermometer into a vessel in which water is boiling, to whatever depth may be requisite to cover the mercury, but upon careful trial we shall find that the mass of boiling water in reality differs in temperature at different depths. This is easily explained; for as the formation of vapour, which constitutes the process of ebullition, takes place at the bottom of the vessel, and as this vapour is thus subject to the pressure of the incumbent mass of water, in addition to the true atmospheric pressure, it follows that it is steam of a temperature more elevated than that at which water just boils in that given state of the atmosphere. The ascent of this steam will, therefore, unduly affect the thermometer which meets with it. It is known, however, that the temperature at which steam issues from the surface of a mass of boiling water under the standard barometric pressure, is exactly the temperature of boiling water. Hence is obtained an accurate mode for the adjustment of thermometers. It requires only that all that part of the instrument which contains mercury should be plunged in steam of this regulated nature; and as the condensation of the vapour upon the glass stem renders the exact view of the mercury a matter of difficulty, and is a source of error, the following simple but convenient apparatus is recommended in the general instructions of the Royal Society, for the graduation of the boiling point upon thermometers. Fig. 5 represents this instrument, consisting of a vessel in which water may be boiled. The mouth *b b* is closed by a lid, into which the thermometer tubes for graduation B B, &c. are inserted. These descend to within a short distance of the surface of the boiling water H, H, and are made to slide through the cork, so that the point M to be marked for ebullition is just above its upper surface: *o o* is another aperture in the vessel for the free escape of steam. It is well also in practice to bear in mind certain facts, with regard to the ebullition of water, mentioned in Art. 9, and which will be more particularly explained hereafter.

(11.) It is evident that if any number of thermometers so constructed be placed first in a bath of melting ice, and then removed to a vessel of boiling water, all the instruments will in both conditions agree in standing at the two fixed points of their scale respectively. And that their indications will be *comparatively* true for all intermediate temperatures, we prove from the following neat proposition of M. Biot.

Let there be two thermometers, with volumes of mercury at the temperature of melting ice V and v respectively. Let the interior diameters of the tubes be R and r; and the intervals between the point of melting ice and boiling water on the stem of each, L and l respectively. Let each of the lengths L and l be divided into the same number a, of equal parts. If now the two thermometers be placed in the same heated medium, the mercury will stand at a height, L_n, above the point of melting ice in the one, and of l_n in the other. And we assert that these altitudes, though unequal, must exactly correspond to the same number of graduated parts or degrees upon each thermometer.

Let δ be the dilatation of mercury from the melting point of ice to the boiling point of water, for a mass of metal taken as unity at the former temperature. Let δ_n be the dilatation of the same mass, between the point of melting ice, and the intermediate temperature to which both the thermometers are exposed. On this notation then $V\delta$ and $V\delta_n$ are the analogous dilatations for the former thermometer, whilst $v\delta$ and $v\delta_n$ are those for the latter; being in proportion to their volumes; and since these dilatations are expressed by cylinders of mercury of known lengths, (calling π the ratio of the circumference of a circle to its diameter,) by estimating the volumes of these cylinders we have

$$V\delta = \pi R^2 L \qquad V\delta_n = \pi R^2 L_n$$

$$v\delta = \pi r^2 l \qquad v\delta_n = \pi r^2 l_n$$

And as the interval L is divided into a degrees, the number of these degrees contained in the interval L_n is $\frac{aL_n}{L}$. Similarly $\frac{al_n}{l}$ will express the number of degrees upon the second thermometer, corresponding to the interval l_n. Now, to prove these expressions equal,

$$\frac{\delta_n}{\delta} = \frac{L_n}{L} \text{ and } \frac{\delta_n}{\delta} = \frac{l_n}{l}.$$

$$\text{Therefore } \frac{L_n}{L} = \frac{l_n}{l} \text{ and } \frac{aL_n}{L} = \frac{al_n}{l}$$

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Hence the two thermometers, when exposed to the same temperature, will mark the same number of degrees, and therefore be capable of comparison or reference the one to the other.

Modes of division.

(12.) Several divisions have been proposed for the thermometric scale, on the interval between melting ice and boiling water; and whatever system be adopted, it is usual to extend the graduations beyond both these points in each direction. The original invention of the thermometer (in the XVIth century) seems to be a disputed point between a Dutchman of the name of Drebbel; Sanctorius, an Italian physician; and the celebrated Galileo. It would appear, however, that the thermometers of all these were of a most limited application; for as they adopted no fixed point of general comparison, the experiments of the one could not be referred to the instrument of the other; each had but his own researches recorded in some terms of the length of his own thermometer stem, and if by accident the instrument were broken all future comparison was lost for ever. It is to Newton that we are indebted for extrication from this state of confusion, as regards the estimation of temperature. He perceived the necessity of some fixed point upon the scale of every thermometer, which might be referred to some unchangeable natural phenomenon, for the purpose of simultaneous verification; and for this reason adopted a ratio between the fluid in the bulb and that in the tube, calling the former 10000, but finally suggested the application of the two points now in use, the melting of ice and the boiling of water.

(13.) We proceed then to the next practical step in the construction of the thermometer, the graduation of the stem. The methods for this purpose depend upon two principles widely differing from each other. In the one, the problem is considered simply the division of a glass tube into spaces of strictly equal capacity, without any reference to the bulb, which may not exist at the time of the graduation, or to the freezing and boiling points, which are independent, and may be a subsequent addition.

Fig. 6.

(14.) Where the tube is of sufficiently large diameter for mercury to be poured into it, the following process is extremely simple and accurate. Let a few bubbles of glass be blown of different sizes, fig. 6, open at both ends; and, of course, as the bubble in the plate is of the full size, having but a minute orifice at each end, made by drawing out the tube heated with the blowpipe and then breaking it evenly off. A bubble is selected, large or small, as the tube may require, and filled by dipping it into a vessel of mercury, and closing each end with the finger and thumb. Thus one measure of mercury may be transferred to the tube, the space it occupies marked with a diamond, and the operation repeated as often as necessary. The absolute capacity of these divisions may easily be calculated if required, by weighing the bubble alone, then the bubble and mercury; and having thus obtained the weight of the mercury filling one division, and knowing either the weight of a cubic inch of mercury, or its specific gravity, compared with water, and the weight of a cubic inch of that fluid, the absolute capacity of the bubble is found. There is also a convenient method of this sort described in Professor Thomson's valuable article on Decomposition, in the Supplement to the *Encyclopædia Britannica.*

(15.) It is evident, however, that such methods are not applicable to the capillary apertures of common thermometer tubes. These are seldom graduated upon this principle; and therefore we omit, for the sake of brevity, M. Gay Lussac's accurate method of dividing such a tube into portions of equal capacity. The reason of this process of graduation being little employed is obvious; namely, that after the tube has been thus divided, it is a mere chance whether both or even one of the points for adjustment fall exactly upon any line of division, after the bulb has been blown and the instrument filled. With a thermometer thus constructed it is necessary to find exactly the freezing and boiling points upon its scale, that is in terms of its degrees, be they what they may, and then by calculation to reduce all the indications of such an instrument to the scale of some other known system of notation, such as that of Fahrenheit, Celsius, &c. For complete information on this head we must refer to M. Biot, (i. p. 46.)

(16.) The mode of division more commonly employed for the stem or scale of the thermometer is this. After the freezing and boiling points have been determined, the intermediate space is divided into any number of equal parts by repeated bisection, or by a dividing engine; this number being determined by the scale we may choose to adopt.

Fahrenheit's. (17.) The division most in use in this country is that of Fahrenheit, which places 180° between the melting point of ice and the boiling point of water. The former is marked 32°, which was estimated by degrees of the same magnitude, counted from the greatest degree of cold which Fahrenheit could produce; this he called 0. The advantage of this scale consists in the degree being of very convenient magnitude for common purposes, neither too large nor too small. The disadvantage which strikes us most forcibly in calculation, consists in the zero point being placed arbitrarily with reference to our present knowledge. In this respect those scales which place zero at the melting point of ice, seem to us to possess a decided advantage.

Reaumur's. In Reaumur's thermometer melting ice is 0, boiling water 80°. "The peculiarity of this scale seems to have arisen from the principle upon which it was constructed. He supposed the liquid in the bulb (weak spirits of wine) equal to 1000 parts at the temperature of freezing water, and the increase of volume to be 80 parts when heated to the point at which water boils. Hence the latter temperature was denoted by this number."

De Lisle's. De Lisle's thermometer was founded on the contraction of mercury in cooling from the boiling to the freezing point of water. Taking the original volume at 10000, the contractions were supposed 150. The scale commenced, therefore, at the boiling point of water, and proceeded to the freezing point, through 150 degrees.

Celsius's. The division proposed by Celsius, a Swede, has been adopted in France, by the name of the Centigrade scale. Zero is placed at melting ice, and 100° at the point of boiling water. This scale is particularly convenient for calculation, but has some disadvantage in the great size of each degree, from which it is frequently necessary to employ fractional or decimal parts.

Murray's. Mr. Murray proposed the adoption of a scale of which the freezing point of mercury should be 0°, and the boiling point of the same metal 1000°. In this scale each degree would be more than half as large as one of Fahrenheit's, and the appearance of the scheme is plausible enough. But it assumes that the dilatations of mercury are uniform throughout, which it will be shown hereafter is not the case through so great an extent of scale.

(18.) In the Appendix, Tables 1, 2, and 3, serve for the reduction of degrees upon one scale to those of another, for the three divisions most in use. The following formulæ are also convenient for the same purpose:

$$C^\circ = \frac{F^\circ - 32}{1.8}$$

$$F^\circ = C^\circ \times 1\ 8 + 32$$

$$R^\circ = \tfrac{4}{9}\,(F^\circ - 32)$$

$$F^\circ = \tfrac{9}{4}\,R^\circ + 32$$

$$C^\circ = \frac{R^\circ}{0.8}$$

$$R^\circ = C^\circ \times 0.8$$

(19.) The method of graduation by continued bisection, or by equal numerical division, though made use of almost invariably, takes for granted that the tube is uniform in capacity throughout. Thermometers thus constructed have certainly a great advantage, in the facility of reading their indications at once from the graduated scale, without an intermediate calculation; but in matters of great delicacy the source of inaccuracy just adverted to must not be overlooked. Our able countryman, Mr. Troughton, makes use of a method in the construction of thermometers which combines the advantages of both the systems we have mentioned. We regret much that he has never made it public other than by verbal communication. The tube is selected with care, and filled in the usual manner; the freezing and boiling points are then ascertained and marked upon the stem; the process for obtaining degrees of absolutely equal capacity, is founded upon the principle of changing the position of a given column of mercury to different parts of the tube. After all, this method seemed to require considerable manual dexterity, which M. Gay Lussac's, depending on the same principle, did not. But the result of Mr. Troughton produces by far the most convenient thermometer.

(20.) Let us now suppose that we have got a mercurial thermometer constructed as well as possible in all points hitherto mentioned, and let it be plunged into a heated fluid. What does the position of the mercury in the instrument tell us? A numerical result according to some conventional notation, which in its comparative reference to other instruments is quite intelligible. Founded, it is true, upon the dilatation of mercury; but not indicating to us precisely the temperature in terms of the dilatation of mercury, but in terms of that dilatation as it takes place in glass which is also dilatable by heat, though in a much less degree. The expression of the thermometer then is the excess of the dilatation of mercury over that of glass, for a given augmentation of temperature.

The apparent dilatation of mercury in glass thus obtained is $\frac{1}{64,80}$ of its initial volume, proceeding from the temperature of melting ice to that of boiling water; and hence, it is evident, the apparent dilatation for one degree upon any given thermometric scale, may easily sulphuric acid, tinged with carmine, being introduced into the ball of the longer tube,) are joined together by the flame of a blow-pipe, and afterwards bent into the shape of the letter U; the one flexure being made just below the joining, where the small cavity facilitates the adjustment of the instrument, which, by a little dexterity, is performed by forcing with the heat of the hand a few minute globules of air from the one ball into the other. The balls are blown as equal as the eye can judge, and from four-tenths to seven-tenths of an inch in diameter. The tubes are such as are drawn for mercurial thermometers, only with wider bores. Fig. 15 represents this instrument: the actual value of its degrees must be ascertained by comparison with the mercurial thermometer, as the range of its scale is seldom made so as to extend from the freezing to the boiling point; so that degrees might be obtained by division." (*n*.)

Fig. 15.

(31.) The freezing point upon the mercurial thermometer has been supposed to undergo some slight variation, so as to appear too low upon the scale of those instruments which have been long made; and it is said, that in such cases the just indication was again recovered by breaking off the end of the stem, so as to admit atmospheric air. Our very accurate countryman, Troughton, examined several very old thermometers, without finding that they had undergone any such change. On this subject consult the following references: (*p*,) (*q*,) (*r*,) (*s*,) (*t*,) (*v*,) (*w*.)

References from (1) to (31) inclusive:

(*a*) Wedgwood, *Phil. Trans.*, lxxiv. p. 310, &c. (*b*) Guyton, Nich. *Jour.*, vi. p. 89, and *An. de Ch.*, lxxiv. and lxxviii. (*c*) Ellicot, *Phil. Trans.*, xlvii. (*d*) Smeaton, *Phil. Trans.*, xlviii. (*e*) Ramsden, *Phil. Trans.*, lxxv. (*f*) Crichton, *Phil. Mag.*, xv. (*g*) Regnier, *Mém. de l'Inst.*, tom. ii. (*h*) Biot, *Jour. des Mines*, xvii. p. 203. (*i*) Biot, *Physique*, vol. i. (*k*) *Report of a Committee of the Royal Society*, &c. *Phil. Trans.*, lxviii. part ii. art. 37. (*l*) Six, *Phil. Trans.*, 1782; Mortimer, *Phil. Trans.*, xliv. p. 689; Frotheringham, *Phil. Trans.*, xlv. p. 129; Fitzgerald, *Phil. Trans.*, li. p. 823; De Luc, *Phil. Trans.*, lxviii. p. 437; Martine's *Essays;* Hale's *Statical Essays*, vol. i. p. 58; De Luc, *Recherches*, &c. i. part ii. ch. ii.; Nollet's *Leçons de Physique*, iv. p. 375; Muschenbroeck, *Inst. ad Nat. Phil.*, ii. p. 625; Cavendish, *Phil. Trans.*, 1757; Cavallo, *Phil. Trans.*, 1781. (*m*) Gay Lussac, *An. de Ch. et de Ph.*, iii. p. 91. (*n*) Leslie's *Inquiry*, &c. p. 9. (*p*) Gourdon, *Bibl. Univ.*, xix. p. 154. (*q*) Flaugergue's *Bibl. Univ.*, xx. p. 117. (*r*) De la Rive and Marcet, *Bibl. Univ.*, xxiii. p. 101. (*s*) Bellani, *Bibl. Univ.*, xxi. p. 252, xxiii. p. 101. (*t*) *Edin. Phil. Jour.*, No. xvii. p. 196. (*v*) Daniell, *An. Phil.*, Oct. 1823. (*w*) Kæmtz, *Jour. für Phys.* &c. *von Schweig.*, vol. x. p. 200. Consult also, On the maximum density of Water, Hælstrom, *Kongl. Vetenskaps Handlingar*, 1823, part ii. p. 193; Crichton, *An. Phil.*, June, 1823, p. 401; Hällstrom, *Kong. Vetensk. Acad. Hand.*, Stockholm, 1824, p. 1; Herapath, on Thermometers, *Phil. Mag.*, Jan. 1824, p. 8; Bessel, on correcting the errors of reading off, *Phil. Mag.*, April, 1824, p. 307; Difference of indication between Thermometers at very low temperatures, in Captain Parry's voyage, *Edin. Jour. of Science*, July, 1824, p. 183; Adams, on the construction of Thermometers, Silliman's *Jour.*, May, 1824; Emmet, on the law of dilatation in liquids, *An. Phil.*, Oct. 1824, p. 254; Butt's improvement of the differential Thermometer, *Trans*
Phil. Soc., vol. i. N. S. 1818, p. 301.

Dilatation of Solids.

(32.) Before we proceed to a review of t
searches, which have at various periods been n
the purpose of ascertaining the absolute laws
tation for various bodies, solids, liquids, and ga
shall find it convenient to examine briefly the
mathematical designations for these dilatatio
in so doing, shall select some of the most in
formulæ from M. Biot's work.

Let δ represent the dilatation of a solid f
unit of *length*, from the effect of some given in
of temperature; then may the dilatation for th
volume, by the same change of temperature, b
sented by $3\ \delta$; so that if the original volume o
or vessel be V, the subsequent volume may be
$(1 + 3\ \delta.)$

For let us suppose an homogeneous mass,
by being dilated by heat becomes V′, the form
the same in both cases; but the volumes of
figures are as the cubes of their homologous sid
is as the cubes of their linear dimensions l, l' n
in the same direction.

$$\text{Hence,} \qquad \frac{V'}{V} = \frac{l'^3}{l^3}.$$

$$\text{And}\ \frac{V' - V}{V} = \frac{l'^3 - l^3}{l^3} = \frac{(l'^2 + l'\,l + l^2).}{l^3}$$

If the linear dilatation $(l' - l)$ be very sm
pared with l, as in the case with all solids at t
tures distant from their fusing points, V′ − V,
tation of volume will also be very small, compa
V, because of the factor $l' - l$, which is its m
in the second member of the equation. So
considering these dilatations so small that we n
regard the first power of the fractions representi
which is almost always sufficiently exact, we
they may be neglected in the factor $l'^2 + l'\,l$
which case $l = l'$, and the factor in this case
$3\ l^2$. Thus the numerator and denominator
divisible by l^2,

$$\text{whence}\ \frac{V' - V}{V} = \left\{3 \,.\, \frac{l' - l}{l}\right\}$$

$\frac{l' - l}{l}$ is the linear dilatation for the unit of len

$\frac{V' - V}{V}$ is the cubic dilatation for the unit of
between the temperatures of the experiment;
by calling the former δ, and the latter Δ, we l
tween these temperatures $\Delta = 3\ \delta$, that is to
cubic dilatation is triple the linear one very ne

(33.) From the above formula, the new volu
body may be readily calculated,

$$\text{for as}\ \frac{V' - V}{V} = 3 .\frac{l' - l}{l}$$

$$V' = V \left\{1 + 3\ \frac{l' - l}{l}\right\}$$

$$\text{or simply}\ V' = V\ (1 + \Delta)$$

(34.) Proceeding in the case of solids, and
that their linear dilatation $\frac{l' - l}{l}$ is constantly

tional to the number of degrees of the thermometer, counted from the freezing point: let V be the initial volume at that temperature, and t be the degrees of temperature, counted upwards from that point. If the linear dilatation for 1 degree $= k$; the linear dilatation for t degrees will be $k\,t$; consequently $V' = V\,(1 + 3\,k\,t,)$ or by making $K = 3\,k$

$$V' = V\,(1 + K\,t)$$

(35.) Should the initial volume V be unknown, it may be deduced from these formulæ after we have obtained V′ by observation; but it is equally just to adopt any other volume for the foundation. For by calling V′ and V″ the volumes corresponding to the temperatures t' and t'', we have similarly

$$V' = V\,(1 + K\,t') \qquad V'' = V\,(1 + K\,t'')$$

where V is always the volume at the temperature of melting ice.

Hence $$V'' = V'\,\frac{1 + K\,t''}{1 + K\,t'}$$

$$= V'\left\{1 + \frac{K\,(t'' - t')}{1 + K\,t'}\right\}$$

But all our present calculations are made on the supposition that the cubic dilatation K is so small, that we need only regard the first power of the fraction that expresses it. Continuing then here the same order of approximation; that is to say neglecting $K\,t'$ in the denominator of the fraction $\frac{K\,(t'' - t')}{1 + K\,t'}$ because the numerator is already of the order K, we obtain simply $V'' = V'\,\{1 + K\,(t'' - t')\}$ that is to say, exactly the same result as if the temperature had been counted from the point t', and from the volume V′, with the constant coefficient K.

(36.) This approximation is, however, only applicable to the case of substances having very small dilatations. If otherwise, the higher powers of K must be employed. Returning to our equation,

$$\frac{V' - V}{V} = \frac{l'^2 + l'\,l + l^2}{l^2} \cdot \frac{l' - l}{l}$$

and confining ourselves to the case of uniform dilatation let $\frac{l' - l}{l} = k\,t$, whence $l' = l\,(1 + k\,t)$ where k is the linear dilatation of an unit of length for one degree of the thermometer. By substituting this value of l' in our equation, and using $k\,t$ for $\frac{l' - l}{l}$ the linear dilatation,

we find $$\frac{V' - V}{V} = (3 + 3\,k\,t + k^2\,t^2)\,.\,k\,t$$

or calling $3\,k = K$ as before,

$$\frac{V' - V}{V} = K\,t\left(1 + \frac{K\,t}{3} + \frac{K^2\,t^2}{27}\right)$$

whence $$V' = V\left\{1 + K\,t + \frac{K^2\,t^2}{3} + \frac{K^3\,t^3}{27}\right\}$$

which formula is complete for substances of great dilatation.

The whole of the above reasoning has proceeded on the supposition, that in each solid the dilatation (be its absolute quantity what it may) is always proportionate to the increments of temperature, measured upon the air thermometer, the only one of invariable accuracy. Whether this assumption be absolutely just, remains to be seen hereafter.

Chap. I.

Dilatation of Liquids and Gases.

Liquids and gases.

(37.) Although the absolute dilatations of these two classes of substances are widely different from each other, yet the formulæ to be investigated are of general application to both. When heat is communicated to a fluid of either of the above-mentioned kinds, the effect produced is expansive. In both cases, however, relative changes are resisted by another force, which we must not always overlook. This force is no other than the pressure of the atmosphere, which is, in fact, present during the expansions of solids, liquids, and gases. In the two former cases, however, its effects are utterly inappreciable; but in the case of aeriform fluids, the atmospheric pressure must frequently form an element in our calculations. The ordinary statics of gaseous bodies do not, it is true, fall within the province of this Article; but, for the reasons just mentioned, we shall find it convenient, to bear in mind certain formulæ, constantly required in these and similar investigations.

Volume and pressure.

(38.) The volume of a given quantity of air, or gas, at a given temperature, is always proportional to the pressure to which it is exposed. Hence if V be the original volume under a pressure p, then under any other pressure p' the new volume,

$$V' = V\,.\,\frac{p}{p'}$$

This refers to air or gas absolutely dry.

(39.) The pressures to which we refer, are those measured by the column of mercury in the barometer, and it is usual to refer the estimated volumes of aeriform fluids, to the volumes which they would possess at a standard altitude of the barometer, viz. 30 inches.

Having then a volume of gas v, the barometer standing at p inches, the volume V referred to the standard altitude is thus expressed,

$$V = \frac{v\,.\,p}{30}$$

If over a trough of mercury.

(40.) But it frequently happens that the air is confined in a jar or tube over mercury, so that the pressure cannot be naturally equal within and without the jar, and the air is dilated.

Let x be the length of the column of air in the tube; h, the total height of the column of mercury and air above the surface of the fluid in the trough; p, the altitude of the barometer; v, the true volume at that pressure; then

$$v = \frac{x}{p}\,.\left\{p - (h - x)\right\}$$

If over a trough of water.

(41.) Should a similar calculation be required for air standing over water, as p refers to a pressure made by mercury, the formula becomes

$$v = \frac{x}{p}\,.\left\{p - \frac{h - x}{13.5}\right\}$$

And it is usual to reduce the value of v thus obtained to that which it would be at the standard altitude of 30 inches by formula in Art. 39.

(42.) We may now proceed to consider the dilatation of fluids by augmentations of temperature.

Let V be the volume of fluid, be it liquid or aeriform, at the temperature of melting ice; where V is instrument was filled with mercury and boiled, for the complete expulsion of the air; after cooling I weighed separately the mercury of the tube and that of the bulb, and thus obtained the ratio of their capacities. The liquid whose dilatation was to be measured was then introduced into the apparatus, and the extremity of the tube was closed at a lamp. Nothing more remains but to compare the march of this thermometer with that of the mercurial thermometer, and this I accomplished by plunging both into a water bath, of which the temperature might be varied at pleasure. I suppose the volume of each liquid at its boiling point to be represented by 1000, and I have estimated the volumes corresponding to inferior temperatures in proportional parts. Table 7 represents the contractions of volume obtained for each liquid.

" The boiling points of each liquid are

Water............	100°.00 C
Alcohol..........	78°.41 C
Sulphuret of carbon	46°.60 C
Sulphuric ether....	35°.66 C

" It may be remarked that these results in the table are not corrected for the contraction of the glass which augments them in a slight degree, because there is another cause tending to diminish them, which it is not easy to estimate; this is the vapour which fills the space left by the liquid, and also the thin film of fluid which moistens the interior surface of the tube. In order the better to observe the progress of dilatation, I have arranged another Table 8 in which the temperature sinks by steps of five degrees, each setting out from the boiling point of each liquid, which is the zero of our scale: the corresponding contractions have been determined by taking the two nearest observations, and supposing their difference to be proportional to that of the temperatures. Besides, the contractions have also been calculated by M. Biot's formula

$$c = \mathrm{A}t + \mathrm{B}t^2 + \mathrm{C}t^3.$$

" From this table it appears, first, that water dilates much less than alcohol and sulphuret of carbon, and both these less than ether. Secondly, that alcohol and sulphuret of carbon dilate equally, as it is only in the first fifteen degrees that there is a slight difference between their dilatations; and this may be attributed to the difficulty of maintaining an uniform temperature at great elevations. Throughout the remainder of the scale, which, for sulphuret of carbon, extends to 60° below its boiling point, or to 13°.4 below freezing point of water, the accordance is perfect. Struck by this unexpected result, and not being able to refer it either to the density or to the very unequal volatility of the two liquids, I was anxious to convince myself that it did not depend upon the densities of their vapours.

" Instead of weights I took equal volumes of each liquid at its boiling temperature, and sought what would be the volume of vapour produced under a pressure of 76 centimetres, and at a temperature of 100°. For this purpose I made use of the following data, furnished by direct experiment.

Density of alcohol	17°.88 ..	0.79235
Density of alcohol	78°.41 ..	0.73869
Density of sulphuret of carbon ..	15°.11 ..	1.2693
Density of sulphuret of carbon ..	46°.6 ..	1.2216
Density of sulphuric ether	24°.77 ..	0.71192
Density of sulphuric ether	35° 66 ..	0.69739
Density of water..............	100° ..	0.96064

" The densities of these different liquids at their respective boiling points are referred to that of water at its maximum, viz. at 3°.89." (*An. de Ch. et Ph.*, i.108.)

Gramme.	Litres.	
1 of alcohol produces	0.661	of vapour at 100°.
1 of sulphuret of carbon	0.402	100°.
1 of sulphuric ether........	0.411	100°.
1 of water	1.700	100°.

From these data it follows, that

Alcohol	78°.41	produces 488.3	of vapour at 100°.
Sulph. carbon	46°.60	...... 491.1	100°.
Ether......	35°.66	...... 285.9	100°.
Water	100°.0	...... 1633.1	100°.

" Upon a comparison of these last numbers we observe that alcohol and sulphuret of carbon produce the same volume of vapour; consequently the densities of the two vapours bear the same ratio to each other, as the liquids do at their boiling points.

" This result, that alcohol and sulphuret of carbon dilate equally and produce the same volume of vapour, is certainly very remarkable; it would seem to warrant the presumption, that there is an intimate relation between the dilatation of a liquid, and the expansion which it undergoes when reduced to the state of vapour. This ratio ought to be independent of the density and the volatility of the liquids, or, at least, ought not to depend upon these properties only, since in alcohol and sulphuret of carbon they differ so widely. Ether and water present no similar appearance; only we perceive that ether, which of the four liquids produces the least vapour, has the greatest dilatation; and that water, which produces the greatest volume of vapour, dilates the least. The contractions of the four liquids, compared together, are not proportional; and the contractions of the same liquid decrease gradually as we recede from their boiling points." (*t*.)

Dulong and Petit.

(55.) We now proceed to examine the first of two memoirs by MM. Dulong and Petit, connected with this part of our subject. It was communicated to the French Institute in 1815. They first inquire, what is to be understood by the word *temperature?* and then, what is the true ratio between the thermometrical indications and the real quantities of heat added or subtracted in producing given changes of temperature?

The instruments at present in use depend upon the dilatations of substances by heat, and to be rigorously exact ought to satisfy two different conditions. The one of being constant in their indications under the same circumstances; and the other of being capable of strict comparison with each other, that is to say, having their motions in just uniformity with the changes of temperature. By care, and well known methods, the former purpose may easily be attained.

With regard to the latter, however, there is much more difficulty; for it is necessary to establish a mode of division such that equal nominal parts upon the scale shall correspond to equal changes of temperature. To fulfil this object completely, it is not enough to ascertain the ratio between the dilatations in the thermometric substance, and the quantities of heat communicated to it; but we ought to be assured that the capacity of the substance for heat undergoes no change, or, at least, ought to be able to estimate that change if it take place. The extreme difficulty of determining exactly how the specific heat of a substance varies, especially at high temperatures, may be regarded as one of the greatest obstacles to the direct solution of this question.

Philosophers have, however, made some attempts to investigate this point: De Luc supposed that the capacity of water did not vary between 0° and 100° centigrade; so that by mixing equal weights of this fluid at different temperatures, the mixture would have its temperature the mean of that of the portion of fluid before mixture. Mr. Dalton proposed the mixture of equal volumes instead of equal masses; because he supposed that the capacity of the same mass augments with the temperature, in proportion to the volume acquired; or, in other words, that the capacity of bodies if referred to their volume is constant.

The method which MM. Dulong and Petit determined first to adopt, was to compare the indications of the mercurial thermometer with the dilatations of air or gas; for it seems proved by the experiments of Dalton and Gay Lussac, that all gases dilate exactly in the same degree under similar circumstances, and consequently it is inferred, that equal increments of volume, are produced by equal increments of temperature.

On this principle, M. Gay Lussac has satisfied himself that the march of the mercurial thermometer is accurate between the temperatures of melting ice and boiling water. It has generally been supposed also, that the dilatation of solids which are of difficult fusion is uniform; and the experiments of MM. Laplace and Lavoisier on metals, seemed to confirm that opinion.

"But," say MM. Dulong and Petit, "if substances so different as the metals and gases follow the same relative law in their dilatations, it becomes extremely probable that these dilatations may indicate the true temperatures; and this may be verified by a comparison with the corresponding quantities of heat."

Our authors then proceed to compare the dilatation of gases with the indications of the mercurial thermometer. It is impossible for us to give in this place a description of their apparatus, or a full detail of these excellent researches, we therefore pass by the numerical results, and quote the following general remarks.

"The results which we now publish, teach us that the dilatation of mercury in the thermometer follows a law which advances upon that of air; so that if we consider the latter as proper for the exact measure of temperatures, we must thence conclude, that the indications of the mercurial thermometer are too elevated at temperatures above the boiling point of water, and the numbers obtained in these experiments may afford the requisite corrections for such indications. These numbers increase with such regularity, that we may without sensible error determine the correction for intermediate temperatures from those comprised in the table."

For two such tables obtained by independent methods we must refer to the original memoir.

"The result of these experiments overturns a doubt which has been raised, with regard to the law of the dilatation of gases. This law has not been expressed in the same manner by MM. Gay Lussac and Dalton, whose researches on this point appeared at the same time. The experiments of M. Gay Lussac tended to prove that the dilatations of gases referred to the mercurial thermometer, are for each degree one constant fraction of the volume at some fixed temperature. Mr. Dalton, on the contrary, supposed that the increment of volume for each equal change of temperature, is some constant fraction of the total volume at the temperature preceding the change. Mr. Dalton does not seem to have confirmed his supposition by direct experiments, but argues in favour of his hypothesis from the extreme simplicity to which it reduces certain apparently complicated laws, such as the law for the cooling of bodies, and that for the variation of the elastic force of vapours.

"We feel certain, however, that the former of these laws has not that simplicity of character which Mr. Dalton supposed, even on the admission of his own hypothesis.

"It is not, however, by reasonings of this sort that we can establish those laws which observation alone ought to furnish. The experiments we have made at high temperatures destroy the hypothesis of the English philosopher; for although these experiments decide nothing with certainty as to the true measure of temperatures, it is at least probable, that the march of the mercurial thermometer ought to be more rapid than that of the temperatures, because in all other liquids the dilatability augments in proportion as they are heated; while on the hypothesis which we now oppose, we should find that mercury on the contrary decreased rapidly in dilatability, according as it became heated; a result altogether opposed to the principles on which Mr. Dalton has founded his theory of the measure of temperatures."

(56.) The dilatations of solids at high temperatures forms the next subject of our memoir. The principle employed is that made use of by Borda long since. The absolute measures of the longitudinal dilatation are not attempted in the first instance by reference to a fixed scale, but by having compound bars formed of two different metals, exposed to the same changes of temperature, the differences of their expansions are ascertained with comparative ease and accuracy. Having formed an instrument of this sort from a bar of platinum and one of copper fixed together at one end, with a vernier at the other extremity, for ascertaining the difference of dilatation, they exposed it to temperatures of 200, 250, and 300 degrees, and made simultaneous observations upon the vernier and the mercurial thermometer. By obtaining the value of one degree upon this metallic thermometer, from a division of the observed dilatation during about the first 100 degrees of heating, they found that by continuing that division, the point of 300° upon the mercurial thermometer would about correspond to 310° upon the metallic thermometer. These experiments, which were frequently repeated with very accordant results, prove that, contrary to the generally received opinion, the progress of dilatation in metals is more rapid than that of the mercurial thermometer. Thus, supposing that the air thermometer, the mercurial thermometer, and the metallic thermometer, had been graduated as above described, when the former marked 300° in its scale the second would point to 310°, and the third to 320°.

It was highly desirable, but a matter of some difficulty, to make a similar comparison with regard to the dilatations of metal and glass, and for this purpose the copper bar was fixed to one of glass. The result of the experiments with this apparatus seemed to prove, that the excess of the dilatation of the copper beyond that of he glass, continued very nearly proportional to the indications of the mercurial thermometer up to the quantity estimated by weight, which a given volume of the fluid undergoes by a given change of temperature. It is a known principle in hydrostatics, that a body plunged into any fluid experiences a loss of weight equal to the weight of the volume of fluid which it displaces. Let a mass of any metal, platinum for example, be affixed to a hair, and weighed in air at a pressure and temperature both given. Its absolute weight will, in this case, be diminished by the weight of the volume of air which it displaces; this loss is so inconsiderable, that let us for the present altogether neglect it, and suppose the weight obtained to be truly that of the platinum in vacuo. For similar reasons we may at present neglect the very slight alteration in apparent weight, which changes in the temperature and pressure of the atmosphere must, strictly speaking, produce. Let the mass of platinum be again weighed, but in water, and the difference between these two weights will give the weight of a mass of water equal in volume to the immersed platinum. But if this experiment be repeated, after the temperature of the water has been changed, the weight will not be the same; because though the weight of an equal volume of fluid, it has undergone a change in its density. From these data then the density or dilatation of the water, or any other fluid, may be deduced.

Let V be the volume of the heavy body at the initial temperature, P the loss of weight by immersion in the fluid at that temperature; which is, in fact, the weight of a volume V of the fluid. Let the temperature be elevated t degrees, and then let P' be the loss of weight which the body sustains; this will similarly be the weight of a volume of fluid equal in volume to the body. But the metal must also have changed its volume, for if the cubic dilatation of its substance be K, its volume V will now have become $V.(1 + K t)$; and this is the volume of liquid which has for its weight P'. Consequently the unit of weight will then occupy a volume $= \frac{V.(1+Kt)}{P'}$, and the primitive mass of which the weight was P, occupies a volume

$$= \frac{V.P.(1+Kt)}{P'}$$

But this changed volume is expressed by $V(1+\delta)$ continuing δ for the cubic dilatation of the liquid between the temperatures employed.

$$\text{Hence} \qquad V(1+\delta) = \frac{VP(1+Kt)}{P'}$$

$$\text{and} \qquad \delta = \frac{P-P'}{P'} + \frac{PKt}{P'}$$

A formula analogous to that obtained for the process of weighing the same vessel filled at different temperatures.

ation.

(47.) Let it be most particularly remembered, that all the preceding formulæ investigated from Art. 32 to Art. 47, and applicable to solids, liquids, or gases, proceed upon the supposition that δ, the dilatation, is constantly the same for similar increments of temperature, even on different points of the thermometric scale. This assumption is not just, except in the case of gases or vapours; but the formulæ are of constant utility for finding the values of δ at different temperatures, and thus investigating the increment or decrement of absolute dilatation, estimated at different points upon the true thermometric scale.

Chap. I.

(48.) The admission made in the last article of the uniform dilatation of elastic fluids, which we found upon the researches of M. Gay Lussac, confirmed by Dulong and Petit, leaves for our consideration the dilatation of liquids only, with the very desirable object before us of discovering some general expression which may, under certain modifications peculiar to each liquid, express the absolute dilatation corresponding to *any* increment of temperature taken upon *any part* of the thermometric scale.

The most satisfactory attempt upon this point has been made by M. Biot, who has constructed an empirical formula, which, compared with the experiments of De Luc, Blagden, Gilpin, and Dalton, presents some very good approximate results. For brevity sake, we are compelled here to exhibit the formula only; but this is the less to be regretted, as the method of its investigation, and the instances selected by the author for its application are rather extensive, and cannot have justice done to them by any abridgement which we can devise, (see *b b*, i. p. 210.)

Biot's formula.

In this formula, $\delta_t = a t + b t^2 + c t^3$, where δ_t is the true dilatation for the unit of volume counted from the temperature of melting ice to the temperature $t°$ on the thermometer, and a, b, c, certain constant coefficients which depend upon the nature of the liquid.

Experimental researches upon the Dilatations of Solids, Liquids, and Gases.

Absolute expansions.

(49.) In speaking of the measures of temperature by the thermometer and pyrometer, we have, in fact, adverted to the researches of numerous and excellent experimentalists, who have attempted to investigate the absolute laws of the dilatation of bodies. Strongly recommending the original memoirs to those who may wish to prosecute such inquiries, we can only now reserve the results which they obtained to be thrown into a general table at the close of this article, and proceed to examine at greater length, though frequently with painful brevity, researches made by equally able philosophers, who, having lived at a subsequent period, enjoyed the advantages of accumulated and recorded experience, of which they have most ably availed themselves. The references to the experiments alluded to will be found at the end of this section; the first pause we make is in passing the name of De Luc, whose *Recherches sur les Modifications de l'Atmosphere, &c.* appeared at Geneva in 1772. His experiments upon the indications of thermometers filled with several sorts of liquids, enable us to obtain some idea of the relative expansions of these fluids in glass. The complaints which he makes of a bubble of air appearing after some time in his thermometers of oil, which he attributes to atmospheric air originally lurking in the pores of the fluid, we conceive may possibly have arisen from an actual decomposition of a minute portion of the oil, or even from vapourisation taking place to a slight extent, though at a comparatively low temperature. (*k*.)

(50.) Sir Charles Blagden's experiments had chiefly for their object the density of water and alcohol at different temperatures. Upon the experiments of Gilpin, Kirwan, and others, Dr. Thomas Young has founded an empirical formula for the dilatation of water, which seems of considerable practical conve-

"The table contains the mean results of a great number of observations made by this process. The first column contains the temperatures as deduced from the dilatation of air; the second contains the mean absolute dilatations of mercury between melting ice, and each of the temperatures indicated in the first column. Lastly, the third column contains the temperature which we should have obtained by supposing the dilatation of mercury uniform; or, in other words, those which a mercurial thermometer would have shown, had it been constructed in some substance, the expansion of which followed the same law with its own."

By comparing the results of the two last tables, we readily perceive that the doubts concerning the course of the mercurial thermometer are not without foundation, and that the laws of dilatation for the instrument itself, and for the liquid contained in it, are materially different,—when we come to estimate a great interval of temperature. When the air thermometer would mark 300° upon its scale, mercury alone would indicate 314°.15, while the common thermometer would point only to 307°.64.

(59.) Upon the preceding data our authors next endeavour to find the absolute dilatation of any solid; because the experimental part of the problem resolves itself into the ascertaining the difference of dilatation between the solid itself and mercury. In the case of glass, for instance, it only requires to find the apparent dilatation of mercury when in glass. This is a question which has frequently engaged the attention of philosophers, and might have been considered as already reduced to some degree of certainty. The results of MM. Dulong and Petit are again presented in a tabular form.

Temperature deduced from dilatation of air.	Mean apparent dilatation of mercury in glass.	Absolute dilatation of glass in volume.	Temperature deduced from dilatation of glass supposed uniform.
100°	$\frac{1}{64,80}$	$\frac{1}{38,700}$	100°
200	$\frac{1}{63,78}$	$\frac{1}{36,300}$	213.2
300	$\frac{1}{63,18}$	$\frac{1}{32,900}$	352.9

The values of apparent dilatation to 200° and 300° as expressed in this table, are deduced from the preceding comparison of the scales of the mercurial and air thermometers. The two first columns need no explanation. The apparent dilatation of mercury in glass between 0° and 100°, appears rather less than that assigned by MM. Lavoisier and Laplace, who state it at $\frac{1}{67,00}$. The third column contains the dilatation of glass obtained as above mentioned. This dilatation is increasing, but from 0° to 100° it came out in the value before assigned by MM. Lavoisier and Laplace. Finally, the last column contains the degrees which would have been indicated by a thermometer formed by a bar of glass, the elongation of which should serve for a measure of temperature. It is evident from the discrepancy which takes place in reaching a temperature of 300°, how far the dilatation of glass is from being uniform.

It is worth stating, that no variations of result were obtained in these experiments when made with common glass tubes from different manufactories, whatever were their calibre or the thickness of the glass.

(60.) We must again refer to the original memoir for the elegant process by which the dilatations of other metals may be estimated and compared, giving, as before, the table of results for iron, copper, and platinum, the metals examined by our authors. The following table contains the mean dilatations of these three metals, taken at first between 0° and 100°, and then between 0° and 300°. No intermediate degree was attempted, the sole object being to assign the direction in which the different thermometric scales deviate from each other. To make these results more intelligible, there is appended to each dilatation the temperature which would be deduced from it, if we were to consider the expansion of the substance uniform. Such, in short, are the temperatures which would be indicated by thermometers constructed with each of these substances.

Temperature deduced from dilatation of air.	Mean absolute dilatation of iron.	Temperature which would be indicated by a thermometer formed of a bar of iron.	Mean absolute dilatation of copper.	Temperature which would be indicated by a thermometer formed of a bar of copper.	Mean absolute dilatation of platinum.	Temperature which would be indicated by a thermometer formed of a bar of platinum.
100°	$\frac{1}{28200}$	100°	$\frac{1}{19400}$	100°	$\frac{1}{37700}$	100°
300	$\frac{1}{22700}$	372.6	$\frac{1}{17700}$	328.8	$\frac{1}{36300}$	311.6

"By comparing these results with those already obtained for glass, we find that the dilatability of solids, as referred to the air thermometer, is increasing, and unequally so for each of them. This fact, which a former memoir pointed out, is thus amply confirmed.

"We believe ourselves in the preceding results to have attained as great a degree of precision as is consistent with measures so delicate; and of this fact some assurance may be obtained by comparing the numbers here given for the dilatations up to 100°, with those that have been published by MM. Lavoisier and Laplace. One remark may be added, that in the direct measure of the dilatations of solids, any error is tripled in passing from the linear expansion to the expansion of volume. The determinations here given produce the latter measure at once, so that any error which may be committed is not multiplied." (*y*)

(61.) Upon the whole, then, we seem to be entitled to conclude,

2. The heat also contracts an adjacent portion of the glass where it does not exist in a sensible state.

3. The heat contracts a part of the glass where it does exist in a sensible state.

4. And the heat expands an adjacent portion of the glass where it does exist in a sensible state. *(ee.)*

References from (32) to (64) inclusive:

(a) Amontons, *Mém. de l'Acad. Par.*, 1699 and 1702. *(b)* Nuguet, *Mém. de l'Acad.*, 1703. *(c)* Ellicot, *Phil. Trans.*, xlvii. p. 485. *(d)* Smeaton, *Phil. Trans.*, 1754, p. 612. *(e)* Roy, *Phil. Trans.*, 1777, lxxv. *(f)* Monge, *Mém. de l'Acad.*, 1786. *(g)* Priestley, *Exp. and Observations*, book vii. sec. 6. *(h)* Saussure, *Hygrométrie*, p. 108. *(i)* Guyton, *An. de Ch.*, i. p. 256. *(k)* De Luc, *Recherches*, &c. i. p. 271, 1772. *(l)* Le Fevre Gineau, *Jour. de Phys.*, xlix. 171. *(m)* Blagden, *Phil. Trans.*, lxxviii. and lxxx. *(n)* Boyle, *Works*, ii. 546. *(o)* Rumford, *Essays*, ii p. 284. *(p)* Hope, *Edin. Trans.*, vol. v. *(q)* Williams, *Edin. Trans.*, ii. p. 23. *(r)* Hall, *Phil. Trans. Edin.*, vol. vi. *(s)* Lavoisier and Laplace, (solids,) *An. de Ch. et de Ph.*, i. 101. *(t)* Gay Lussac, (liquids,) *An. de Ch. et de Ph.*, ii. 136. *(u)* Dulong and Petit, (solids,) *An. de Ch. et de Ph.*, ii. 240. *(v)* Gay Lussac, *An. de Ch. et de Ph.*, iii. *(w)* Guyton and Prieur, *Jour. de l'Ecole Polytech.*, cahier ii. *(x)* Dalton, *New Syst. Ch. Phil.*, p. 11; also *Manch. Memoirs*, vol. v. p. 598, 1802; Nicholson's *Journal*, xiii. 337, and xiv. 128. *(y)* Dulong and Petit, *An de Ch. et de Ph.*, vii. 113, 225. *(z)* Gay Lussac and Welther, *An. de Ch. et de Phil.*, xix. p. 436. *(aa)* Emmet, (liquids,) Thomson's *An.* Oct. 1824; Thenard, *Syst.* sec. 39 to 47, and sec. 53; Thomson's *Chemistry*, i. p. 27 to 45; Murray's *Chemistry*, i. p. 201 to 261. *(bb)* Biot, *Physique*, vol. i. ch. i. vi. viii. ix. and x. *(cc)* Gay Lussac, *An. de Chimie*, xliii. p. 137. *(dd)* Young's *Lectures on Nat. Phil.*, ii. p. 392. *(ee)* Brewster, *Phil. Trans.*, 1814, p. 436; 1815, p. 1; 1816, p. 46—114, and 157—179. *(ff)* Ferrussac, *Bulletin*, sec. 1, Feb. 1824, p. 101.

§ 2. *Fusion and Solidification.*

(65.) So far as either our means are adequate to the experiment, or our judgment can be correctly guided by analogy only, we are led to suppose that it may be considered as a universal law of nature, that by a sufficient elevation of temperature every substance which is originally solid might be reduced to the fluid state. It is true, that in practice we fall far short of this result, partly because the heat which we can produce by artificial means is of very limited extent, and partly from other properties in the constitution of bodies which interfere with such a consequence. It has, however, been found that every increase which has been made in our powers for the excitement of intense heat, whether by the pile of Volta, or by the gas blowpipe, has placed various substances in succession under the operation of this law, which before formed practical exceptions to it, and it can scarcely now be said than any absolutely infusible body is known to exist. Among the most infusible are some of those bodies which the present state of our knowledge calls simple or elementary; such are carbon, and some of the rarer metals; but it frequently happens that those which in that state are thus refractory, become easy of fusion when combined with other bodies. Thus pure lime is far more difficult of fusion than its carbonate. Those interfering properties to which we have above alluded depend generally upon chemical affinities, by which it happens that long before a sufficient degree of heat can be applied, some new combination is formed upon the subversion of the original one. In plain terms, many substances burn before they melt. This forms no exception to the general tendency of the law. There is, however, an exception of this sort, that some substances when acted upon by heat proceed *per saltum*. Thus arsenic when heated does not liquefy but passes at once to the aeriform state. Not so ice, or frozen mercury, for these bodies first liquefy, and then at a subsequent period of temperature are vapourised. In speaking of the fusing point of bodies, we must bear in mind the comparative nature of our scale and our terms; we are, in fact, only talking of what happens to us experimentalists living in a world of a certain mean temperature; and it requires no great stretch of our imagination to conceive two worlds, the mean temperatures of which expressed even on our own thermometric scale should be such, that in the one every substance we now know as a fluid should be a solid; while in the other every solid we find around us should exist in the fluid state.

In some cases the passage of a solid into the fluid state, upon the application of heat, is made immediately without any intermediate process of softening; such is the fusion of ice, frozen mercury, and some of the metals; and it has been well remarked, that this process chiefly holds with these bodies, which in congelation affect a crystalline structure. Other bodies, on the contrary, seem to change gradually from solid to liquid, passing through every intermediate degree of cohesion; but still it seems an established fact, that the temperature of fluidity is constant for each individual substance. This point, with reference to many substances, is exhibited in the general table of the effects of heat, No. 4, Appendix.

(66.) The complete explanation of the state of fluidity, with reference to the general physical laws of matter, is not so easy a task as might at first be supposed. It has long been stated, that fluidity depends upon the effect of caloric, which first expands bodies, that is to say, removes their integrant molecules to a greater distance from each other, until at length the power of cohesion being overcome, perfect mobility among the molecules brings the substance under the laws and definition of a fluid. Doubtless the effect of caloric is the great force opposed to, and frequently overcoming cohesion; but Professor Robison has urged that this explanation is not adequate to all the circumstances of the case. For it does not account for this fact, that many crystalline solids actually contract in the process of fusion, which is quite at variance with the hypothesis. He remarks also, that "to explain the mobility of a fluid, or the facility with which its parts are separated, it is necessary to suppose only that the action of its particles, whatever it may be, is equal in every direction at the same distance; as, if this equality exists, no force can be required to move an adjacent particle from one situation to another; nor any force required to keep the particle in its new situation, with regard to the rest of the fluid. And still the attraction exerted between the particles, provided it be equal, may be strong. On the other hand, in a solid, the particles must attract more strongly in one direction than in another; hence a particular situation of each particle must be assumed, and a force, more or less great, cold, the weakest part freezes, while a stronger portion remains liquid; so that by the action of cold they are separated into two portions differing very much in strength. But when they are very much diluted the whole mixture undergoes congelation; and in that case it appears that the freezing point of water is lowered by mixing it with acid rather in a greater ratio than the increase of the acid. The following table exhibits the freezing point of mixtures of various weights of sulphuric acid, of the density 1.837, temperature 62°, and of nitric acid of the density 1.454, with 100 parts of water:

Sulphuric acid.		Nitric acid.	
Proportion of acid.	Freezing point.	Proportion of acid.	Freezing point.
10	24.5	10	22
20	12.5	20	10.5
25	7.5	23.4	7 (*c.*)

"The concentrated acids themselves undergo congelation when exposed to a sufficient degree of cold; but each of them has a particular strength at which it congeals most readily. When either stronger or weaker the cold must be increased. The following table, calculated by Mr. Cavendish from Mr. Macnab's experiments, exhibits the freezing points of nitric acid of various degrees of strength. The strength being indicated by the quantity of marble necessary to saturate 1000 parts of the acid. (*d.*)

Strength.	Freezing point.	Difference.
568	− 45.5	+ 15.4
538	− 30.1	+ 12
508	− 18.1	+ 8.7
478	− 9.4	+ 5.3
448	− 4.1	+ 1.7
418	− 2.4	− 1.8
388	− 4.2	− 5.5
358	− 9.7	− 8.0
328	− 17.7	− 10.0
298	− 27.7	

"The following table exhibits the freezing points of sulphuric acid of various strengths. (*e.*)

Strength.	Freezing point.
977	+ 1
918	− 26
846	+ 42
758	− 45

"Mr. Keir had previously ascertained that sulphuric acid S. G. 1.78 at 60° freezes most easily, requiring only the temperature of 46°. This agrees nearly with the preceding experiments, as Mr. Cavendish informs us, that sulphuric acid of that S. G. is of the strength 848. From the preceding table we see, that besides this strength of easiest freezing, sulphuric acid has another point of contrary flexure at a superior strength; beyond this, if the strength be increased, the cold necessary to produce congelation begins again to diminish." (*f.*)

(69.) The tables exhibiting the point of vapourisation of fluids, may also be resorted to for the purpose of ascertaining the point at which those vapours, upon a reduction of temperature, pass to the liquid state. The fusing points of metals, &c., Table 4, are of course also their temperatures of solidification upon the scale of descending temperature.

With regard to the gases, which have been ca permanently elastic fluids, merely with reference to ordinary temperatures, recent experiments confirm supposition of their following the general law, assuming the liquid form upon a sufficient reductio temperature. The great heat which they give out u violent condensation, renders it probable that t aeriform state is in a great measure dependent u caloric. The only one of these fluids, however, has been liquefied by cold alone, is ammoniacal which, according to Guyton, assumes the liquid at 54° Fahrenheit.

For the congealing point of some other liquids, the General Table Appendix, No. 4.

References. (*a*) Blagden, *Phil. Trans.*, 1788, p. (*b*) Ibid., p. 277. (*c*) Ibid., p. 308. (*d*) Cavend *Phil. Trans.*, 1788, p. 174. (*e*) Ibid., p. 181. Thomson, *Chemistry*, i. p. 51.

§ 3. *Vapourisation.*

In this section we shall consider *Evaporation* true *Vapourisation* of fluids at their boiling point.

(70.) By the application of heat, a very considera number of bodies, both solid and liquid, may be co verted into the form of gaseous matter; and as lo as that elevation of temperature continues, the form an elastic fluid is retained. It is clearly proved that this state they are liquids in combination with calo by which change a new order of properties is impres upon them. Of this action common steam or vapour of mercury are examples.

But in all such cases a depression of temperat causes the elastic fluid again to assume the liquid solid form from which it originally set out.

It has been usual to divide elastic fluids into *pern nent gases* and *vapours*, the former being known onl the aeriform state, except in combination. Ammo however, it has long been known, might be reduced the liquid form by a sufficient depression of temperatu and Mr. Faraday has recently shown, that by dis gaging several of the gases from their state of com nation, under such pressure that the elastic form co never be assumed, they might be exhibited as liquid

On the whole there is every reason to conclude fr analogy, that every solid in nature might be "mel with fervent heat," and by a further accession of te perature pass to the state of an elastic fluid. And same suppositions would lead us to think, that which we now know in the gaseous and liquid fo might by a sufficient cold be reduced to the solid sta By human means it is hardly probable that either these results should be obtained.

(71.) The essential distinction between *gas* a *vapour* may be thus stated:

A *gas* is not reducible to the liquid state by any tainable pressure *alone;* is therefore capable of in finite condensation; and, under such circumstanc the volume is always inversely as the pressure.

A *vapour* of a given substance can contain o some definite quantity of that substance within a gi volume, which quantity varies with the temperature.

Thus, comparing a given space filled with gas, another saturated with vapour, at a given temperatu if we suppose that space to be diminished, the will be compressed, and its elastic force or resista will be increased; but the *vapour* will be partly temperature. When these elastic fluids are exposed to heat, unconnected with the liquids from which they are produced, they undergo precisely the same increase of bulk as air or gas does, when subjected to a similar change of temperature. But when the elastic fluid is in contact with the liquid from which it was produced, the specific gravity of the vapours increase with the elasticity. From the experiments of Mr. Sharpe (*b*) and Mr. Southern (*c*) it would appear that the increase of specific gravity is proportional to the elasticity. On the supposition that this is actually the case, the following table gives us the specific gravity of steam at different temperatures, when in contact with the hot water from which it was generated.

Temperature.	S. G. of steam.
212	0.4545
250.3	0.9090
293.4	1.8180
343.6	3.6360

Where the specific gravity of air at 60° is reckoned unity." Thomson.

(78.) A simple illustration will show the propriety of a division, which we shall follow M. Biot in introducing at this point of our subject. Its object is to show, the necessity of considering the elasticity of pure vapours apart from the same property, when they are mixed with atmospheric air. Fig. 16 represents a common condenser gage, formed of a bent tube, open at one end and closed at the other, containing some mercury. Moisten the interior of the tube with water, and observe the tension; then place the instrument in warm water of known temperature, and again observe the tension; it will be seen that the depression of the mercury in the sealed end is greater than it would have been by an equal increment of temperature, when filled with dry air or gas only. Hence, elastic vapours mixed with air add to its elastic force. Again, if we take a common test tube, and contrive to fill it with some vapour, (permanently so, at the temperature and pressure under which we make the experiment,) and having placed the open end of the test tube on the surface of the mercurial bath; if we gradually sink the tube perpendicularly in the fluid, we observe that the mercury is not depressed, but retains the same level both within and without the tube. This we know would not be the case with air or gas, but is here effected by a portion of the vapour being reduced to the fluid state, so that what remains in the test tube has the same density and elastic force as at first. The experiment may be continued until all the vapour is condensed.

It will tend to simplification then if we first consider,

The elastic force of pure vapours in vacuo.

(79.) The earliest scientific publication that entered into this question minutely, was given by Professor Robison, in the *Encyclopædia*, article Steam, and has been republished in the collection of his philosophical writings by Dr. Brewster. (*d.*) It was known also, that similar researches had been made by Mr. Watt, but they were not made public at the time, and the comparatively recent publication just mentioned, is, we believe, the only place in which any account of them can be found. (*e.*)

(80.) At length our distinguished countryman, Dalton, published a most valuable series of experiments on this subject in 1802. (*f.*) They extend up to the boiling point of water only, but he has attempted to continue the law much higher by calculation. Southern's experiments on the same subject were made under the direction of Mr. Watt in 1803, but not published till some years after. Another series at Paris by M. Betancourt, of which we have only seen the results. (*h.*) Some confirmations of Dalton's experiments were obtained by MM. Biot and Berthollet Jun. (*g.*) And lastly, an interesting paper by Dr. Ure in the *Phil. Trans. for* 1818. (*i.*) Such are the sources from which the following abstract will proceed. A general tabular view of all their results will be given in the Appendix from Thomson's *Chemistry*. No. 5.

Mr. Dalton.

Mr. Dalton's process has the merit of great simplicity. He made use of a graduated barometer tube filled with mercury as usual, and carefully deprived of air by boiling. While the tube remains with the open end upwards, and nearly filled with mercury, the remaining space is to be occupied with water, or other fluid to be examined. The tube is then to be reversed, so that the liquid may moisten the interior, and by raising the open end of the tube again, more mercury may be poured in so as to fill the tube entirely. On raising this tube vertically, the mercury will sink, as in the common barometer, but the depression will be greater; for the altitude of the mercurial column will be equal to the altitude of the mercury in a barometer, minus the depression due to the elasticity of the vapour produced within the tube by the liquid. All the liquid in excess which does not pass into vapour, will form a small stratum at the top of the mercurial column. Hence, for that fluid and at that temperature, the elastic force of the vapour is known; and by contriving to surround that portion of the barometer tube which contains the vapour with hot water, the elastic force at other temperatures was determined. By this process may be measured all degrees of elastic force inferior to that produced by the common atmospheric pressure; but for higher temperatures and greater pressures, the barometer tube was bent into the form of a syphon, and the fluid with its vapour being confined in the shorter tube, its elastic force was measured by the length of the column of mercury, which it would support in the longer tube, at the temperature of each experiment.

Such is a very brief notice of the method of Mr. Dalton's experiments, the results may be seen in the table. M. Biot has attempted to deduce from them an empirical formula, to express the elastic force of the vapour of water at all temperatures. He considers that it may be of the form

Biot's formula.

$$\log F_n = \log 30 + a\,n + b\,n^2 + c\,n^3$$

where F is the force, n the thermometric degrees, and a, b, c, constant coefficients relating to the fluid employed: and that it is not necessary to go beyond the third power of n, from the extreme smallness of the coefficient. The formula with these coefficients inserted as deduced from Dalton's experiments, where n relates to centigrade degrees, counted from the boiling point; those descending on the scale being called plus, and those ascending minus.

$$\log F_n = \log 30 - 0.01537419550\,n - 0.00006742735\,n^2 + 0.00000003381\,n^3$$

and the same notation reduced to Fahrenheit's scale becomes

$$\log F_f = 1.4771213 - 0.00854121972\,f - 0.00002081091\,f^2 + 0.00000000580\,f^3$$

elastic force of the fluid at a given temperature is inversely proportional to the volume which it occupies. Hence if, at a given temperature, we reduce two cubic feet of a gas which supported a pressure of 30 inches of mercury to a volume of one cubic foot, the elasticity will be double, that is to say equal to 60 inches of mercury. Here, then, the elasticity of the one is added to the elasticity of the other; and this rule is general for all mixtures of dry gases.

(91.) But further, the law extends to mixtures of vapours with each other, and of vapours with gases; provided that no chemical action take place between any of the substances employed. Hence this general proposition, that in a mixture of elastic fluids, of whatsoever kind, having any number of such fluids which each separately sustain pressures of p, p', p'', &c. respectively, if we take a volume V of each, and add them together in a vessel of the same capacity V, the elastic force of the mixture will be the sum of the individual elastic forces, that is to say it will equal $p + p' + p'' +$ &c.

Should the vapours in such cases be in a state of saturation for that given temperature, and should the volume V be diminished by compression, they each follow the law of their nature, and some portion is condensed; so that the exact saturation, density, and elastic force due to that temperature are maintained.

But, on the other hand, should the volume V be increased, if the vapours be in contact with the liquids from which they are formed, more vapour will rise to reproduce the constant elastic force, &c. due to the temperature. And if the vapours be not so in contact with fluids, they then suffer dilatation by the increase of volume like gases, and their elastic force decreases according to the general law.

And in all these cases the air or gases must each proceed according to that law; their elasticity being in proportion to their volume, provided the temperature remain constant during the experiment.

These propositions admit of elegant experimental demonstration, and all depend upon properties developed in Mr. Dalton's papers on these subjects. (*p*.)

(92.) If a liquid be placed in a vacuum of given capacity, or in a vessel of the same capacity filled with dry air or gas, vapour is produced in both cases, with this difference only, that in the former it is developed to the maximum extent instantly, but in the latter it requires some little time to produce saturation. In both cases the quantities supplied to a given space, and at a given temperature, are the same; as that quantity depends on temperature only. It would appear as if air produced some mechanical resistance to the ascent of vapour, from the absolute inertia of its molecules.

Evaporation.

Evaporation

(93.) The process of evaporation cannot, in a strict philosophical view of the question, differ from vapourisation; for both depend upon the same physical laws. The former is, in fact, a particular case of the latter; in it atmospheric air is always supposed present, and the operation may comprise one or more fluids.

It has been a matter of discussion, whether the phenomenon of evaporation were produced by a chemical affinity between the molecules of air and the molecules of the liquid evaporated. The experiments of Saussure, De Luc, and Dalton, enable us, however, to account for all the phenomena that take place, without having recourse to such a supposition.

(94.) We may view the atmosphere at any given place, in the light of a mass of air in contact with a mass of fluid; let the temperature of both be the same, and the exposed surface of the fluid, water for instance, is all we need consider; then, as from meteorological causes which do not now concern us, the atmosphere has always some aqueous vapour in it, let us trace this in different circumstances. The elasticity of vapour depends, as we have already seen, upon its temperature; now if we suppose the atmosphere at a given temperature saturated with moisture, it is evident that any depression of temperature will produce the condensation of a portion of the vapour, which must return to the liquid state.

But in the most common state of the atmosphere saturation does not exist; still, as it is never without the presence of some aqueous vapour, if we gradually reduce the temperature of atmospheric air, we shall at length arrive at that temperature which exactly corresponds to the elasticity of the atmospheric vapour; and if we continue the reduction, we produce the condensation of vapour in the form of dew; thus arriving at the former case.

(95.) Hence arises a useful meteorological problem. Having given the temperature of the atmosphere, and the reduction which must be made in that temperature to produce the deposition of moisture, it is required to find the elasticity of the aqueous vapour in the air originally? This question Mr. Dalton's researches have enabled us to solve, as we shall perceive hereafter. (*a*.)

(96.) We have remarked that saturation does not usually exist in the atmosphere, and hence if those liquids, water, alcohol, ether, &c. which easily pass into the state of vapour (or as we say, *with reference to our common temperatures*, undergo spontaneous evaporation) be exposed, they will constantly emit vapour from their surface. Hence, in such a state of the atmosphere, an exposed surface of water at the same temperature as the air, is constantly undergoing evaporation. Among other circumstances producing an influence upon that operation, is the motion of the air from winds or other causes constantly removing the vapour already formed from the surface of the water, and thus accelerating the evaporation; for the present, however, we consider the case of air in a quiescent state.

Thus the most general problem for solution is, to determine the *rate* of evaporation within a mass of air, supposed of indefinite extent; knowing the quantity of vapour already contained in it, and the quantity which produces saturation at the temperature of the experiment.

(97.) Mr. Dalton first endeavours to estimate the rate of evaporation in water under a calm state of the atmosphere, and at the boiling point. For this purpose he suspended a small cylindrical vessel of tin by three wires. This vessel contained water, and was $2\frac{1}{2}$ inches in diameter. The surface thus exposed may be considered infinitely small, when compared with the whole extent of the atmosphere; so that the total quantity of the liquid evaporated may be considered as proportional to the area of that surface, all other circumstances being the same. The wire support served to hold the vessel over a lamp, or small fire, so as to produce ebullition; and also to hang it to the end of a scale beam in order to ascertain the loss of weight sustained by boiling.

The water is first made to boil, the vessel is then removed and weighed, and then again boiled for a certain number of minutes measured by a stop-watch, then again removed and weighed. The total loss in grains, divided by the number of minutes, gives the loss per minute in grains also. In experiments of this sort extreme rigour would require that the atmosphere should always contain naturally the same quantity of vapour, that the results obtained at different times might be comparable; or, at least, that the humidity should be estimated and taken into the account by calculations. But since the proportion of vapour existing naturally in the air is very small, and, consequently, has but a feeble degree of elastic force, compared with that of boiling water, it follows that it can have only an almost imperceptible influence upon the results obtained at high temperatures, so that at least as a first approximation this point may be neglected.

The stillness of the atmosphere in which the experiment is made, seems a much more important consideration; for the rate of evaporation in a perfectly quiet room was found by Mr. Dalton to be only two-thirds of what it was in the strongest draught he could obtain in a house.

Mr. Dalton's experiments, extending from the boiling point down to 138° Fahrenheit, are given in the following table, to which the corresponding elasticities are affixed:

Temperature in degrees of Fahrenheit.	Elastic force of vapour in inches.	Evaporation per minute in grains.
212°	30.00	30
180	15.15	15
164	10.41	10
152	7.81	8.5
144	6.37	6
138	5.44	5

From this table we perceive that the quantity of evaporation at each temperature is proportional to the elastic force of the vapour which is forming. Such a result might well be expected in the case of air perfectly devoid of vapour at first; but it is reasonable to suppose that the initial vapour in the atmosphere ought to modify the process of evaporation; and such is, in truth, the case; but its influence is not perceptible in experiments like those now related, because the elastic forces of the vapours evolved are very great in comparison with that of the vapour naturally existent in the atmosphere; and the more so, as Dalton undertook these researches at low atmospheric temperatures, when the air must have contained but little moisture.

This circumstance must, however, not be overlooked in calculating the phenomena of evaporation for temperatures below those of the above table. Suppose, for instance, that we wished to apply the same law at the temperature of 60° Fahrenheit, where the tension of vapour, if at its maximum, would be only about $\frac{1}{60}$ of that at ebullition; and if, by chance, at the time of the experiment the atmosphere were at the same temperature, and saturated with moisture, the quantity of evaporation would be by no means $\frac{1}{60}$ of that corresponding to the temperature of ebullition, as the ratio, according to the elastic force, might indicate; for, in fact, it would be nothing.

(98.) To estimate the influence of the humidity of the atmosphere, Dalton endeavoured to obtain a method for measuring the quantity of vapour existing in it at the time of the experiment. This he performed by pouring into a cylindrical glass some water at different temperatures, in succession, all below that of the atmosphere; by which he learned the exact degree of the thermometer, at which the humidity of the atmosphere began to be deposited as dew upon the exterior of the glass vessel. Having obtained that temperature, he calculated the elastic force of the vapour corresponding to it; and this force being reduced again to that due to the atmospheric temperature at the time, by the common law for gaseous dilatation, gave precisely the elasticity of the aqueous vapour in the air originally.

For example, let the temperature at which dew is deposited be t', where the original temperature of the atmosphere was t; and let ϕ' be the force of vapour corresponding to temperature t', as given in the tables, that is to say the force to which the vapour in the air is reduced by refrigeration; then we have but to dilate this quantity ϕ' as a gas, to obtain the true tension f' of the vapour in the air originally.

$$f' = \phi' \, \frac{(1 + t \,.002083)}{1 + t' \,.002083}$$

Where t is reckoned in degrees of Fahrenheit.

In these calculations it is immaterial whether we consider the experiment as made upon a given volume of air confined in a vessel, or, as with Mr. Dalton, use the cooling of a substance to obtain the deposition of dew in the indefinite mass of the atmosphere. And this is precisely the problem proposed in Art. 95.

(99.) The solution of this problem is, in fact, the determination of an important meteorological question, to which certain instruments, called Hygrometers, have long been applied. Dalton's experiment gives an absolute estimate of the tension of aqueous vapour in the atmosphere at any time; that is to say, determines its hygrometric state. The mode of performing the experiment has been improved by Mr. Daniell; and hygrometers on this construction are now sold by the philosophical instrument-makers in London.

(100.) Having obtained the value of this important correction, we return to Mr. Dalton's investigation of the rate of evaporation. Since the formation of vapour at inferior temperatures must be less rapid, especially when impeded by comparatively large quantities of humidity already in the air, it became necessary to employ a larger surface, that the evaporation might be more perceptible. The cylindrical vessel for the water had now a diameter of six inches, and the experiments were conducted as before.

The law of the results obtained may be thus expressed. Let f be the maximum tension which vapour could acquire for the temperature of the experiment, (viz. that producing saturation.) Then Mr. Dalton found, that under the same state of the air with regard to its agitation, the quantity of evaporation was constantly proportional to $f - f'$; that is to say, if the total tension of vapour at 212° be called F, and that at that tempe-

It has long been remarked that the process of distillation is much retarded if the communication between the retort and the vessel in which the refrigeration takes place be through a small aperture; in this case, the current of vapour has to force a passage in opposition to the constant resistance of the body of air within the refrigerant vessel. Again, it has been remarked by M. Gay Lussac, that in the distillation of zinc from a vessel having but a small orifice, the operation does not proceed without the fused metal be actually in ebullition; but that the distillation goes on even at much lower temperatures, from a mixture of oxide of zinc and charcoal. Thus gaseous oxide of charcoal is formed, which by its expansive force carries away with it the vapours of the zinc as rapidly as they are formed, thus making room for further vapourisation, and the process is accelerated.

In those evaporations which are conducted on the large scale in several sorts of manufacture, it is found, as might be expected, that the larger the surface exposed, and the more free the communication with external air, the more rapidly is the operation performed. And as it is obvious that the pressure of a mass of vapour incumbent on the surface of a liquid must impede the process of evaporation, it is frequently advisable to allow a current of air to pass over the surface of the liquid, for the purpose of removing the vapour as fast as it is formed.

Again, we have formerly remarked (23) that thermometers of alcohol or water, if well made, so as to be quite free from atmospheric air within, might be employed for the measure of temperatures considerably above the boiling points of those respective fluids. In the dilatation of these liquids by heat, they emit freely from their surfaces, that is to say, from the extremity of their columns as much vapour as the vacant part of the tube can contain; and as this vapour can rise from the surface freely, without any effort, because it expands into a vacuum, or else into vapour already existing, we perceive that there is no reason for the formation of vapour from the interior of the liquid also. For, supposing the temperature uniform throughout the instrument, such vapour formed within the liquid could only possess an elastic force equal to that of the vapour within the void space of the stem; and besides this equal, and therefore, counterbalancing force, it would have to overcome the weight of the incumbent column of liquid; this being impossible, the formation of vapour constituing ebullition does not take place in the interior. But if air were mingled with the liquid, the case becomes altogether changed; for the elasticity of that air, increased by heat, would be added to the elastic force of the vapour formed within the liquid. Thus ebullition might commence whenever the sum of these two interior forces exceeded the elastic force of the vapour within the stem, plus the weight of the column of fluid incumbent upon the nascent bubble of vapour and air; or, in short, whenever the elasticity of the bubble of air surpassed the weight of the column of liquid incumbent upon it.

A very beautiful practical application of the dependence of the boiling point of fluids upon the atmospheric pressure, has been made by the late Archdeacon Wollaston. He constructed a thermometer having but a small range of temperature, and that extending some degrees from the boiling point of water downwards, but with these degrees so large as to be capable of accurate subdivision. It is obvious, that from the diminution of atmospheric pressure in ascending a mountain, the temperature at which water boils is also diminished. Hence, it is evident, that by boiling water over a small lamp, at the bottom and top of a mountain, and carefully estimating the temperatures, the relative heights may be determined. (*q*.)

References from (65) to (106) inclusive.

(*a*) Gay Lussac, *An. de Ch. et de Ph.*, March, 1818. (*b*) Sharpe, *Manch. Mem.*, Second Series, ii. p. 1. (*c*) Southern, in Brewster's edition of Rob. *Mech. Phil.* (*d*) Robison, *Ibid.* (*e*) Watt, *Ibid.* (*f*) Dalton, *Manch. Mem.*, v. p. 563. (*g*) Biot, *Physique*, ch. xiii. xiv. xv. and xvii. (*h*) Betancourt, *Jour. de l'Ecole Polyt.*, ii. p. 47. (*i*) Ure, *Phil. Trans.*, 1818, p. 338. (*k*) Creighton, *Phil. Mag.*, May, 1819. (*l*) Dalton, *Man. Mem.*, New Series, iii. p. 474. (*m*) Gay Lussac, *An. de Chim.*, xci. p. 95 and 150; Ibid. *An. de Ch. et de Ph.*, i. p. 218. (*n*) Thenard, *Mém. d'Arcueil*, i. p. 121. (*o*) Biot, *Phys.*, ch. xiv. vol. i. p. 291. (*p*) Ibid. ch. xv. p. 300. (*q*) Wollaston, *Phil. Trans.*, 1817, p. 183. Also consult De Luc, *Phil. Trans.*, and Saussure, *Voyages, &c. and Hygrométrie.* (*r*) *An. Phil.*, April, 1823, p. 313.

§ 4. *Incandescence.*

(107.) The effects of caloric hitherto described, are those dependent upon an increase of distance between the integrant molecules of bodies. Incandescence, or, as it is sometimes termed, Ignition, seems to be utterly independent of such a mode of action. Solids are capable of it, so that they do not pass to the state of vapour, nor enter into combustion before they arrive at the temperature proper for luminous emanation. Liquids too are supposed to pass under the same law, but must be confined to prevent their assuming the state of vapour. No experiments have, however, as yet exhibited the gases in a luminous state from artificial heat, though the flash seen in the dark upon the discharge of an air-gun is a fact that ought to be well considered, before we pronounce such an extension of the law impossible. The term ignition we conceive objectionable, because it is commonly appropriated to the commencement of combustion.

Incandescence seems to be produced at one invariable temperature in the same substance, at least in the absence of other light, or in light of given intensity; it is independent of the presence of air, for it has been made to take place within a mass of melted glass; it is permanent, so long as the exciting degree of heat continues, and after having disappeared, is again renewable by a repetition of the process by which it may have been originally developed.

Absolute incandescence is preceded by an emission of red rays of light; and the temperature at which this phenomenon takes place, is supposed to be the same for all substances. Mr. Wedgwood having gilded some lines upon a piece of porcelain, luted it to the end of a tube, which was placed within a heated crucible. The substances were extremely dissimilar in their nature, but no difference could be perceived in the time at which the gold and the earthenware both became luminous. Newton estimated the temperature of a red heat just visible in the dark to be at 635° of Fahrenheit; a full red heat 752°; and absolute incandescence visible in day light to be beyond 1000°. Irvine esti mated the heat of a common coal fire at 790° or 796°. (*a.*) Mr. Wedgwood placed the point of red heat visible in the dark at — 1° of his pyrometer, or 947° Fahrenheit; and he placed incandescence visible in day light at 1077° Fahrenheit. The progress of heating first elicits the red, then yellow, and finally absolutely full white light.

Mr. Wedgwood fully proved that the same temperature which renders solids luminous, has not the same effect upon air. He passed a current of air through an earthenware tube in a state of incandescence, the air was thus conducted into a globular vessel, from which it again escaped through an opening at the top. In the side of this vessel was a glass, through which whatever passed within could be observed. The air was not luminous, and yet it was of sufficient temperature, for it rendered a gold wire incandescent, which was suspended in its current. (*b.*)

The incandescence produced by percussion and attrition, seem to us to fall only within the general law of a certain effect being produced by a certain increment of temperature, no matter how it may have been developed.

References to Art. 107.

(*a*) Irvine's *Chemical Essays*, p. 33. (*b*) Wedgwood, *Phil. Trans.*, 1792, lxvi. p. 504 and p. 39.

DIVISION II.

Chemical Effects of Heat.

Chemical effects.

(108.) The extent to which this subject will here be pursued is by no means proportionate to its importance. This Division might indeed without impropriety have been altogether omitted, but its title is retained for the purpose of clearly pointing out that which to us appears the connecting link between Physical and Chemical Science, as far as Heat is concerned.

As soon as Heat, applied to any substance, has ceased to affect its physical state only, and has commenced a true chemical action, we hold that the subject no longer falls under the legitimate consideration of this article. We have strictly confined our researches into the *effects* of Heat, to those which act upon the *integrant* molecules of all bodies; and we refer to the department of chemical science, all those effects which take place upon the *constituent* molecules. This latter explanation may at first sight appear inappropriate, with reference to simple substances, which possess integrant molecules only in our sense of the word. But, in truth, the instant chemical action commences, the presence of an integrant molecule of some other simple or compound substance is implied: and thus the molecule in our supposed case, though an integrant and simple one at first, becomes a portion of a constituent one, in union with others which it may have met with.

Under this view of the subject, the *Chemical Effect of Heat* is to produce a change in the affinities of the atoms or molecules of matter. By the influence of such a change, either in quantity or intensity, compositions and decompositions are effected: the elements of simple bodies are made to unite; or those of compound ones are compelled to separate themselves.

Substances which at one temperature may remain in contact without entering into combination, will by a change of temperature enter into intimate and permanent chemical union. Thus, at ordinary temperatures, a lump of bismuth and a lump of lead show no tendency to unite; but let both be heated in a ladle, and combination commences with the fusion of the one, even below the temperature required for the fusion of the other. In other cases, where a true chemical combination is supposed already to exist; yet the physical effects of an increase of temperature upon the elements may be so dissimilar as to produce a force over-powering that of the affinities of the bodies; and a separation is effected by removing the constituent molecules beyond the sphere of their natural chemical attraction. Of this sort of effect, the decomposition of chalk, and the separation of mercury from some of its alloys, by the application of Heat, are instances. But in the case of an alloy of gold with silver, as the constituent molecules of neither element are capable of volatilization by any Heat we can apply, no decomposition is effected.

Let Combustion be defined as it may, Inflammation differs from it in this particular, that it is combustion taking place under the form of flame. In a piece of wood that is burning, we see both inflammation and combustion; but in a piece of charcoal we observe combustion without inflammation. These are, however, chemical phenomena, and must be studied as such in a future article; wherein *Heat*, though admitted an important agent, is, nevertheless, only an agent in common with Light and Electricity.

CHAPTER II.

ON THE SOURCES OF HEAT AND COLD.

In language of greater precision we should say, that this chapter is devoted to an examination of those natural sources or artificial methods, to which we are in the habit of resorting, for the purpose of producing elevation or depression of temperature in bodies. These will be considered under the following sections:

§ 1. The Sun.

§ 2. Electricity.

§ 3. Mechanical Action.

§ 4. Change of Temperature by change of Physical condition.

§ 5. Variations of Temperature produced during simultaneous Physical and Chemical change.

Animal Heat, accompanying vitality, might, perhaps, also be mentioned; but it would be impossible to examine its dependencies without encroaching upon the province of the Physiologist.

§ 1. *The Sun.*

(109.) The sun is the most obvious and unvarying source from which heat is communicated to our earth. Its action is modified in a thousand ways, but its operations and effects are ever present. To the Astronomer we leave all those difficult, and yet undecided questions, relating to the nature and substance of that luminary, and confine ourselves to a brief statement of those operations which are immediately connected with our subject. How far the heat and light of the sun are separable, or the contrary; whether they be of different natures, or only modifications of the same property or substance, we do not as yet pause to inquire, but we describe the effects of the solar beam in its ordinary state.

When transparent bodies are exposed to the light of the sun, it is well known that the heating effect is greatly inferior to that which is produced upon opake substances. Those bodies which, like coloured glasses, intercept some part of the sun's light only, have, roughly speaking, a similar partial effect upon the passage of its calorific rays; and the less the quantity of heat transmitted, the greater is the quantity absorbed by the coloured medium. Opake bodies, which all equally and totally resist the passage of light, are not equally affected in temperature by its incidence upon them. That modification of their nature which produces in us the sensation of colour, developes in them also a corresponding difference in the absorbing power, or capability of imbibing caloric from the appulse of light. This was made the subject of experiment by Hooke, Franklin, and more recently by Sir H. Davy. Dr. Franklin placed some square pieces of cloth of different colours upon a surface of snow, and noted those for the best absorbers of caloric which sunk in most deeply by melting the snow.

Sir H. Davy exposed to the sun, one side of six copper plates, which had been painted of different colours. To the opposite side of each plate, a bit of cerate adhered, which melted at a temperature of 70° Fahrenheit. The wax melted on the coloured plates in the following order. First black, then blue, green, red, yellow, and lastly on the white. (*a.*) It is obvious, that this order is, as far as our sight is concerned, the reverse of the illuminating power of the reflected rays. The black copper absorbed most heat, as is proved by the experiment; and judging by our vision, it absorbed all the light. To what extent do these properties coincide?

Chap. II.

Effects of colour.

(110.) We shall have to examine hereafter the widely different effects of coloured substances in the absorption of caloric, when radiating from a body artificially heated; but for the present content ourselves with stating, that this law seems very nearly if not quite true with the solar beam; that its calorific effect produced by direct impact varies inversely as the quantity of illuminating power reflected from surfaces differing in colour.

On this subject the following simple experiments may be cited in illustration. Cavallo found that a thermometer with a blackened bulb stood higher than one with its bulb not blackened; whether exposed to the sun's rays, the light of day, or the light of a lamp. (*b.*) M. Pictet also found that two thermometers, one blackened, the other not, manifested the same temperature in the dark. (*c.*)

(111.) Different substances acquire different increments of temperature by exposure to the sun's rays, and these depend on many adventitious circumstances. It is said that in these climates few bodies are able to manifest more than 120° Fahrenheit. M. Saussure constructed a small box, lined with cork, and charred internally, so as to be a good absorber and a bad conductor of heat. The box, enclosing a thermometer, was covered with a disc of glass. By exposure of this apparatus for a few minutes to the direct rays of the sun, the thermometer stood at 221° Fahrenheit; the temperature of the external air being 75°. (*d.*) With an arrangement somewhat similar, Professor Robison frequently obtained an elevation of 230° Fahrenheit, and once of even 237°. Before a bright fire the thermometer rose to 212°. (*e.*)

(112.) Such are the effects of a sunbeam in its ordinary state, but by the application of those processes by which its light is concentrated, an analogous effect is produced upon its calorific properties. A convex lens of diaphanous matter, or a concave *metallic* speculum, will by this method of condensation set fire to combustible bodies, or fuse the most refractory substances. Indeed the heat produced by such means is almost as intense as by the powers of the Voltaic pile, or by the energy of the gas blowpipe. Count Rumford proved by experiment, that this great increase of power is not the effect of any change in property from the altered direction of the rays, by thus concentrating them into a focus, but was due solely to the increased intensity of action, arising from the accumulation of numbers, thus brought to bear upon the same point. (*f.*)

The dissimilar calorific effects of the different parts the prismatic spectrum will be found under the more tended Chapter upon Radiation.

References from (109) to (112) inclusive.

(*a*) Beddoes's *Contributions*, p. 4. (*b*) Cavallo, *hil. Trans.*, 1792. (*c*) Pictet, *Essai sur le Feu*, ch. iv.) Saussure, *Voyages, &c.*, ii. p. 932. (*e*) Robison, lack's *Lect.*, i. p. 547. (*f*) Rumford, *Jour. de Phys.*, i. p. 32. (*g*) Herschell, *Phil. Trans.*, 1806, p. 286.) Englefield, *Jour. Roy. Inst.*, i. p. 203.

§ 2. *Electricity.*

(113.) The instantaneous restoration of electrical quilibrium which takes place in a common discharge, as been long known as a source of caloric; and some the most intense degrees of heat that have ever been itnessed sprung from the action of the Voltaic pile. or the agency of common electricity in the developent of Heat, we have but to refer our readers to the ticle ELECTRICITY, ch. vi. art. 179. Those details hich are entered into there with propriety, would here absolutely out of place.

There is, however, a very curious experiment of M. ictet, which proves that Electricity, in addition to its nmediate calorific effect by discharge, exerts a singular fluence upon the communication of caloric. This ble experimentalist exhausted a glass globe of 200.199 cubic inches capacity, till the manometer ithin stood at 1.75 lines. In the middle of the globe as a thermometer suspended from a glass stand. The lorific effects of two lighted candles were concentrated pon the thermometer bulb, by means of two concave flectors. The globe and the candles were all placed pon the same insulated stool. An electrical machine, anding 2½ feet from the globe, had its conductor conected with a brass ring at the mouth of the globe, so at an electrical atmosphere could be kept up within e globe, and even extending to some distance round , as M. Pictet inferred from the candles burning dimly. he experiment commenced with the thermometer at 9°.8. Electricity being communicated, the thermoeter rose to 70°.2 in 732 seconds. The experiment eing repeated without the electricity, it required 1050 econds to produce the same rise in the thermometer. t would seem then, that the electrified state increased e rate of the communication of caloric; though it ppeared from other experiments, that the maximum mperature producible by each method was the same.

The candles were then insulated, by being placed on iscs of varnished glass. In the electrified vacuum e thermometer rose from 52°.2 to 74°.7 in 1050 econds, but in the unelectrified vacuum in 965 seconds. he maximum temperature that could be obtained in e electrified vacuum was 77°, but in the unelectrified ne 86°. Hence it appears, that when the globe and andles are in electrical communication, electricity ccelerated the transmission of caloric; but that when ey were on separate insulators, the contrary effect of tardation was produced. (*a.*)

(114.) Another fact worthy of notice is mentioned y Thomson, that when metals are heated to incandesence by electric energies, they continue to evolve light nger than if heated by common fire; other circumtances remaining the same. (*b.*)

References for (113) and (114).

(*a*) Pictet, *Essai sur le Feu*, ch. vi. (*b*) Thomson's *hemistry*, i. p. 160.

§ 3. *Mechanical Action.*

(115.) There are nominally three modes of mechanical action by which heat is developed,—*percussion*, *condensation*, and *friction*. The two former, perhaps, are identical, and may be considered only as differences of phrase, arising from the varied nature of the bodies submitted to experiment. Thus, *percussion* seems to apply but ill to the molecules of a gaseous fluid, and yet possibly the heat evolved during the condensation of that form of matter, may be justly referred to the mutual percussion of its particles. Again, *condensation* may not appear the most appropriate term to apply to the hammering of a metal, a process by which heat is evolved; and yet condensation is the invariable accompaniment of this action, and may possibly be essential to its production.

Friction has by some been supposed to produce its effects upon the principle of its inducing a state of momentary condensation, but of this hereafter. We are now only desirous of showing that these three modes of action are sufficiently nearly allied to each other to be permitted to fall under the same section of our article.

Percussion.

(116.) If a piece of iron be struck with a hammer, the metal acquires a sensible elevation of temperature, and by repeated blows it may be made red hot. Again, in the common process of striking a light with flint and steel, the heat is evolved by percussion; and to such an extent, as to determine a chemical combination between the minute fragments of metal separated, and the oxygen of the air. These fragments are not luminous in vacuo, from the absence of the air which is essential to combustion.

The elevation of temperature produced in metals by percussion is said to be attended by condensation, that is, their density is increased. The best set of experiments on this subject has been made by Biot, Berthollet, and Pictet. The following is Professor Thomson's abstract of their memoir:

"The experiments were made upon pieces of gold, silver, and copper, of the same size and shape; and care was taken that all the parts of the apparatus had acquired the same temperature before the experiments began. Copper evolved most heat, silver was next in order, and gold evolved the least. The first blow evolved the most heat, and it diminished gradually, and after the third blow was hardly perceptible. The heat acquired was estimated by throwing the piece of metal struck into a quantity of water, and ascertaining the change of temperature which the water underwent. The following table exhibits the increase of temperature experienced by two pieces of copper from three successive blows:

1st blow . .	1st piece.	17°.44
	2nd do.	20 .80
2nd blow . .	1st piece.	7°.30
	2nd do.	3 .69
3rd blow . .	1st piece.	1°.90
	2nd do.	1 .46

"The whole quantity of heat evolved by each of these pieces of copper is nearly the same; that from the first piece being 26°.64, and that from the second 25°.95.

"The following table exhibits the heat evolved from two pieces of silver treated in the same way:

an air-pump. By means of this machine a piece of corundum was made to rub against a steel cup in air; sparks were produced in great abundance during the whole time, but the thermometer did not rise. The same experiment was repeated in the exhausted receiver of an air-pump, (the manometer standing at 4 lines;) no sparks were produced, but a kind of phosphoric light was visible in the dark. The thermometer did not rise. A piece of brass being made to rub in the same manner against a much smaller brass cup in air, the thermometer (which almost filled the cup) rose 0°.3, but did not begin to rise till the friction had ceased. This shows us that the motion produced in the air carried off the heat as it was evolved. In the exhausted receiver it began to rise the moment the friction commenced, and rose in all 1°.2. When a bit of wood was made to rub against the brass cup in the air, the thermometer rose 0°.7, and on substituting also a wooden cup it rose 2°.1; and in the exhausted receiver 2°.4, and in air condensed to $1\frac{1}{4}$ atmospheres it rose 0°.5. Pictet, *Essai sur le Feu*, ch. ix.

"If these experiments be not thought conclusive, I have others to relate which will not leave a doubt that the heat produced by friction is not connected with the decomposition of oxygen gas. Count Rumford contrived, with his usual ingenuity, to enclose the cylinder above described in a wooden box filled with water, which effectually excluded all air, as the cylinder itself and the borer were surrounded with water, and at the same time did not impede the motion of the instrument. The quantity of water amounted to 18.77 pounds avoirdupoise, and at the beginning of the experiment was at the temperature 60°. After the cylinder had revolved for an hour at the rate of 32 times in a minute, the temperature of the water was 107°; in 30 minutes more it was 178°; and in 2 hours and 30 minutes from the commencement of the experiment the water actually boiled. According to the computation of Count Rumford, the heat produced would have been sufficient to heat 26.58 pounds of ice cold water to the boiling heat; and it would have required nine wax candles of a moderate size, burning with a clear flame all the time the experiment lasted, to have produced as much heat. In this experiment all access of water into the hole of the cylinder, where the friction took place, was prevented. But in another experiment the water was allowed free access, with precisely the same results." (*f*.)

The experiments of Rumford were repeated and diversified by M. Haldot. He contrived an instrument by which two bodies could be pressed against each other by means of a spring, while one of them turned round with a velocity of 32.8 inches per second. The friction took place in a strong box, containing 216 cubic inches of water. The results obtained so nearly resemble those of Count Rumford, that it is unnecessary to enter into more particular details. The rubber was brass. When the metal rubbed was zinc, the heat evolved was greatest; brass and lead afforded equal heat, but less than zinc; tin produced only $\frac{7}{8}$ of the heat evolved during the friction of lead. By quadrupling the pressure, the heat evolved was seven times greater than before. When the rubber was rough, it produced but half as much heat as when smooth. When the apparatus was surrounded by bad conductors of heat, or by non-conductors of electricity, the quantity of heat evolved was diminished. (*g*.)

From some experiments upon the heat evolved during the friction of different kinds of wood upon each other, given in Nicholson's *Journal*, it would appear that the increase of temperature is not in any ratio direct or inverse of their hardness. (*h*.)

Mr. Wedgwood found, that by pressing a piece of window-glass against a revolving wheel of grit, the glass became red hot at the point of friction, and gave off sparks capable of inflaming gunpowder, these then must have been particles of glass heated to redness at least. (*i*.)

"The heat then which appears, in consequence of friction, is neither produced by an increase of the density nor by an alteration in the specific heat of the substances exposed to friction, nor is it owing to the decomposition of the oxygen gas in the atmosphere. Whence then is it derived? This question cannot at present be answered; but this is no sufficient reason for concluding, with Count Rumford, that there is no such substance as caloric at all, but that it is merely a *peculiar kind of motion*. Were it possible to prove that the accumulation of heat by friction is *incompatible* with its being a substance, in that case Count Rumford's conclusion would be a fair one; but surely this has not been done. We are certainly not yet sufficiently acquainted with the laws of the motion of heat, to be able to affirm with certainty that friction cannot cause it to accumulate in the bodies rubbed. This we know at least to be the case with electricity. Nobody has hitherto been able to demonstrate in what manner it is accumulated by friction; and yet this alone has not been thought a sufficient reason to deny its material existence. (*k*.)

"One would be apt to suspect the agency of electricity in the following experiment by M. Pictet. Into one of the brass cups, formerly described, a small quantity of cotton was put to prevent the bulb of the thermometer from being broken. As the cup turned round, two or three fibres of the cotton rubbed against the bulb, and without any other friction the thermometer rose five or six degrees. A greater quantity of cotton being made to rub against the bulb, the thermometer rose 15°." (*l*.)

Sir H. Davy recently contrived to melt ice by friction within an atmosphere which was not suffered to rise above the temperature of 32° Fahrenheit.

References from (115) to (122) inclusive:

(*a*) *Mém. d'Arcueil*, ii. p. 441; or Thomson's *Chem.*, i. p. 148. (*b*) Nicholson's *Journ.*, iv. p. 280; and ix. p. 302. (*c*) Desmartiers, Nich. *Journ.*, xxxiii. p. 227. (*d*) Biot, Nich. *Jour.*, xi. p. 303. (*e*) Rumford, *Essays* (*f*) Rumford, Nich. *Jour.*, xi. p. 106. (*g*) Haldot, Nich. *Jour.*, xxvi. p. 30. (*h*) Nich. *Jour.*, viii. p. 218. (*i*) *Phil. Trans.*, 1792, p. 45. (*k*) Thomson's *Chem.*, i. p. 154. (*l*) Thomson's *Chem.*, p. 156. (*m*) *Phil. Trans.*, lxxviii. p. 43. See Morosi, *Mém. de l'Institut de Milan*, tom. xiii. p. 137—147.

§ 4. *Change of Temperature, by change of Physical condition.*

(123.) Changes in the physical state of bodies are intimately connected with alterations in their inherent quantities of caloric. But in some cases the sensible temperature is altered, while in others it is not so. In the preceding chapter we have noticed many changes

y the operation of heat,
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fully in this question we ought to be acquainted
doctrines of latent heat, but as these cannot
ied, except in a series of experiments wherein
ysical change is frequently produced artificially
addition or abstraction of caloric; and, at other
, by its own spontaneous action may be considered
rce of heat or cold, we must leave this most im-
tant question for the more ample details of a separate
pter. For the present, therefore, we only adduce
me striking general illustrations of this species of
ction, not considering whether the changes of tem-
perature produced be dependent upon latent heat or
not.

(124.) The ordinary freezing point of water is 32° Fahrenheit; but Sir Charles Blagden managed to cool it down to 21°, and Mr. Dalton to 5° Fahrenheit before solidification took place. But if in this state of things the water be agitated, or a morsel of ice be added, either of which will determine the instant solidification, a thermometer inserted instantly rises to 32°. Heat then was evolved by the act of crystallization.

(125.) A precisely analogous instance is afforded by preparing a hot saturated solution of Glauber's salts, which is to contain the bulb of a thermometer, and must be corked closely while still hot; it is well to avoid agitation here also. When the vessel has become cold, admit the atmospheric air by piercing the cork. Crystallization instantly takes place, and the thermometer indicates considerable elevation of temperature, so great indeed as to be sensible to the hand.

It is, in fact, by no means improbable, that the effects
duced during ordinary solidification and regular
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ture. At all events
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the presence of chemical affinity is
we shall see a similar effect from the analogo
tion of an aeriform fluid passing into the liquid state.

(127.) In the converse process, during which a liquid passes to the state of vapour, or a solid to the state of liquid, as much caloric is essential to the operation, it is rapidly absorbed from the surrounding bodies, and, of course, reduction of temperature is produced.

Cold by evaporation.

The cold excited by evaporation was observed by Wilcke and Mairan, and still more accurately investigated by Cullen. He dipped the bulb of a thermometer in alcohol, and remarked that the mercury fell during the evaporation of the spirit, and returned to its original elevation after that process had ceased. Other liquids were found to produce the same effect, and this in the order of their volatility; thus, the greatest cold which he obtained was from ether. He found also, that the diminution of temperature was rendered greater by increasing the rate of evaporation. By directing a current of air upon the thermometer bulb, when moistened with water, the mercury fell 5° Fahrenheit; by using alcohol 12°, and by employing sulphuric ether it fell more than 30°. (*a.*)

By wrapping a piece of linen round the bulb of a thermometer, and exposing it to a brisk current of air, after it has been dipped in ether, a fall of 45 may be produced below the ordinary temperature of a room. Alcohol, similarly applied, will sink it from 50° to 31°, and water to 38°. (*b.*)

On this principle is a neat experiment of Dr. Cullen. Let about half an ounce of ether be put into a wide mouthed bottle or small jar, and let a test tube of thin glass, containing eight or ten drops of water, be suspended, so that the part of the tube with the water may be just dipped into the ether. If this apparatus be placed under the receiver of an air-pump, and the air be rapidly exhausted, the ether will evaporate so rapidly as to boil, and in this process will rob the water of so much caloric, as to convert it into a mass of ice. Dr. Higgins states, that in a frosty day he produced a cold of 40° below the freezing point of water by this method. (c.) By the same process, Dr. Marcet effected the freezing of mercury. He subsequently found that he could produce a still greater degree of cold by a similar application of a more volatile compound, the sulphuret of carbon. This indeed forms the readiest method with which we are acquainted, for exhibiting a small quantity of mercury in the frozen state. It requires only to surround an elongated thermometer bulb of very thin glass with cotton wool. This bulb is to pass into the receiver of an air-pump; for which purpose a receiver, open at top, and fitted with a perforated brass plate, is extremely convenient. The cotton is then moistened with sulphuret of carbon, and the exhaustion of the receiver conducted as rapidly as possible. The freezing of the mercury is readily observed by its great and instantaneous contraction at the instant of congelation.

Leslie's

(128.) We are indebted to Professor Leslie for some very ingenious experiments founded upon these principles. (*d.*) When the evaporation of a fluid is accelerated by placing it in vacuo, the vapour which
med from it, acts by its elastic force in retarding
of the evaporation, and a continuance of
ustion, is necessary to remove this
fficulty by introducing some
absorb the vapour.

mbination, as to produce the union of the gaseous ements on a large scale with detonation.

(136.) Sometimes the platinum wire is coiled round e wick of a spirit lamp, so as to leave a few coils free ove the cotton. The lamp is lighted for the purpose heating the wire, and then blown out; the wire, wever, continues its operation, and will glow as long any spirit remains to produce vapour, and be con- med.

In the more delicate of these experiments, platinum d palladium were the only metals found to succeed. or this preeminence they were indebted to their low gree of specific heat, and the imperfection of their nducting power. (*a.*)

In these cases we remark, in the first place, chemical mbination, and then a great physical change, viz. ndensation from the gaseous to the liquid state, as ater is part of the result.

The preceding section was confined to those appre- able physical changes which were obviously indepen- nt of chemical action. Under this head there may course be included both simple and compound sub- ances; but the change which the latter may undergo ust be confined to their integrant molecules, and must t extend to their constituent ones. Within the nits of our definition we seem to be able to refer to e examples already cited in sec. 4 with confidence.

(137.) But if, on the other hand, we had in this ction wished to speak of calorific effects arising from emical action alone, and from which physical action as to be absolutely excluded, we should not have een able to adduce examples with an equal degree of nfidence. That chemical action alone, unaccompanied y physical effect, (if it ever so exist,) may produce reat calorific effects, we fully believe, for we think it early proved, that heat is a frequent result of the utual action of substances possessed of strong chemi- l affinities. The following are instances of this kind, herein physical action is either inappreciable, or is by o means adequate to account for the calorific effects eveloped.

(138.) Let a few copper or lead filings be mixed ith a little sulphur, and placed in the closed end of a lass tube; then hold the part containing the mixture ver the flame of a lamp. At a certain elevation of tem- erature, combination will take place, and this with the ppearance of vivid combustion; light and heat being opiously evolved, though the tube be removed from he flame of the lamp. The presence of oxygen is uite unnecessary to this experiment. Heat also is volved in forming an alloy of potassium, with either rsenic or tellurium.

(139.) Again, M. Berzelius discovered in 1811, that everal antimoniates with metallic base, when they are eated nearly to redness, exhibit a sudden and vivid low of heat. He ascertained also that oxygen was ot necessary to the effect, and that no change of weight was produced in these salts by the operation. Dr. Wollaston pointed out a similar phenomenon in gadolinite, and Berzelius in the oxides of chromium, tantalum, and rhodium, with many other bodies. The only appreciable change produced in all these cases, is that the substances so acted upon are rendered insoluble in those acid or alkaline menstrua to which they had been before subject.

Chap. II.

Physical and chemical change tending to the same effect.

(140.) It might at first sight appear a reasonable supposition, that whenever the chemical and physical effects harmonize together, that is, whenever by the chemical action heat is evolved, and at the same time a great condensation of volume is effected, the total calorific result would be increased. And this is true in many cases, but is directly opposed by the indisputable evidence of others. Of these modes of action we adduce the following examples.

(141.) Let one volume of oxygen gas and two volumes of hydrogen gas be united by detonation, from the effects of an electric spark, so as to form water. Here is very violent chemical action, and the passage of the whole volume of mixed gases from their original state to that of a liquid; and the heat produced is very great.

(142.) Again, if we add a lump of amalgam of bismuth to a lump of amalgam of lead, though both are originally solid, or nearly so, yet by a little trituration the whole becomes liquid, and considerable cold is produced; an effect according with the physical action, but, as far as we can tell, independent of, or even possibly opposed to, the effect of the chemical action. See also ref. (*o.*) (*p.*)

Physical and chemical action opposed.

(143.) The converse case is that in which the chemical action is attended by some considerable physical effect, from which latter a marked elevation or depression of temperature might be expected, and yet the change of temperature takes place in a direction immediately opposite to that anticipated by the application of a general physical law. Thus the following instances go to prove, that chemical action, accompanied with great expansion of volume, do not produce cold.

(144.) If a vessel, containing the protoxide of chlorine (euchlorine) be exposed to the sun's rays, or to artificial heat, the gas is decomposed with explosion, the volume of the mixed gases is increased in the ratio of 3 to 2, and yet light and heat are evolved.

(145.) A similar effect is produced in heating oxide of rhodium, obtained from the soda muriate. Water is first given out, and subsequently a further decomposition takes place, by the escape of one portion of the oxygen, leaving a metallic suboxide. But during this passage of oxygen from the solid to the gaseous state, the remaining oxide is seen in a state of ignition.

(146.) The chloride of azote (azotane) is an oily looking fluid, and yet by its decomposition the gaseous elements acquire a volume 600 times as great as in the fluid state, yet light and heat are evolved by the explosion. The extreme violence of the action, and the danger of the experiment, present however some difficulties in the way of a minute examination of the circumstances.

(147.) The nitrates and chlorates in deflagration with metallic bodies, or with sulphur, phosphorus, charcoal, &c., undergo a great enlargement of volume, and yet produce light and intense heat. The firing of gunpowder is a familiar, but striking example. It consists of nitre, sulphur, and charcoal. The detonation may be performed in vacuo, the product being for the most part gaseous, the volume in this state is many hundred times greater than in the original solid form, yet light and heat are copiously evolved.

(148.) By dissolving some pounded marble in sulphuric acid, the heat evolved is very considerable, although the evolution of carbonic acid gas must tend to produce a depression of temperature. But if caustic lime be employed, this counteracting cause is cut off, and the heat evolved becomes very considerable indeed.

In an experiment of this sort, MM. Lavoisier and Laplace mixed 1.5 pound of water at 0° with 2 pounds of sulphuric acid of specific gravity 1.87051 also at 0°. The heat thus evolved melted 3.1406 pounds of ice. If we divide this product by 3.5 pounds, we obtain 0.8973 pound, the quantity of ice melted by one pound of the mixture.

On the contrary, some substances in combining absorb caloric instead of evolving it. These must be raised to some common temperature t, so high that even after their combination they shall still remain above 0°. The mixture is then made within the calorimeter, and the quantity of ice is measured which the mixture will melt in cooling down to 0°. The mixed mass must then be again heated to t°, and placed within the calorimeter, noting the quantity of ice melted as before. Now it is obvious, that the difference between the ice melted in the two cases, arises from the cold produced in the process of combination. Hence, the ice melted in the latter case, minus the ice melted in the former, gives the quantity of ice which is due to the difference of effect in the two cases, and this may be divided by the total quantity of the substances, to obtain a result analogous to the former one.

To absolute measures thus obtained, we shall have to return shortly.

(152.) The physical changes then, which some or other of them are the frequent concomitants of chemical action, are *solidification*, *condensation*, *liquefaction*, *vapourisation*, and *combustion*. Of all these, instances have been adduced, for the purpose of proving the uncertainty of any general law arising out of a physical change, when that change is combined with chemical action. But after these illustrations we come to a practical view of the subject, with reference to the specific object of this section. We have to describe those processes, chiefly chemical, which, with reference to the ordinary temperatures in which we live, may be termed sources of heat and cold.

(153.) For elevation of temperature, that which is best known to us, and is of the readiest application, is COMBUSTION. It may be necessary here to state, that for the sake of avoiding those difficulties and conflicting opinions which arise out of the attempts to define combustion, we here use it only in its ordinary and familiar acceptation. It will fall to the province of pure chemistry to provide a strict definition for that term, and to enter upon the question of what varieties of chemical action are truly expressed thereby.

(154.) Different substances enter into combustion at different temperatures; but as our present object is to consider the burning of bodies as a source of heat, for practical application, we ought to know something of their relative powers for that purpose. On this head, however, the information afforded by numerous experiments, and those performed by very distinguished philosophers, is by no means so satisfactory as we could desire. Dr. Crawford attempted to estimate the heat evolved during the combustion of given weights of certain substances, by surrounding them with water, and estimating its increase of temperature. (*c*.)

(155.) Lavoisier and Laplace attempted the same thing by measuring the quantity of ice melted by various substances during their combustion. These experiments were made with the calorimeter already described. To effect this purpose, it was necessary that the air within the cold enclosure should be changed, being partly absorbed or altered by the combustion. By conducting the process in an atmosphere not much above zero, the introduction of a fresh quantity of such air will bring no sensible accession of heat, and, consequently, will not vitiate the results. This renewal of air should only be made when absolutely necessary, in order that the air confined within may have ample time to part with all the increase of temperature which the combustion has communicated to it. The introduction of fresh air is easily made by a pair of common bellows, of which the pipe only passes into the chamber of the calorimeter, the valve remaining without. We might even, for greater accuracy, not force the air immediately into the calorimeter, but previously pass it into a confined vessel, surrounded with ice, so as to reduce its temperature actually to 0°. Another tube may be employed for the casual emission of the air from within.

The following experiments were made by MM. Lavoisier and Laplace with every precaution. The quantities of ice melted are expressed in decimals of the French pound.

	lb.		lbs of Ice.
Combustion of	1	of hydrogen gas melted....	312
	1	of olive oil	148.883
	1	of white wax............	140.000
	1	of phosphorus	100.000
	1	of carbon	96.351
	1	of lard	95.813
	1	of sulphuric ether........	74.313
Deflagration of	1	of saltpetre with 1 of sulphur	32.00
	1	of nitre with 0.3125 charcoal	12.00

(156.) In the same manner it is obvious that experiments may be conducted for ascertaining the heat communicated to air by the respiration of animals. (*d*.)

(157.) Count Rumford, in a similar series of researches, employed for a calorimeter a metallic vessel filled with water of a given temperature. This vessel was made of thin sheet copper, 8 inches long, 4½ inches broad, and 4¾ deep, fig. 19. The interior contained a worm tube of the same material, which made three horizontal revolutions, and was designed for the reception of the gaseous products, by which the water was to be heated. This circulating tube was in the form of a flat pipe, half an inch in depth throughout, 1½ wide at the mouth, and 1 inch at the other orifice. The mouth consisted of a circular tube, 1 inch in diameter, and 1 inch in depth. By this (which also extended upwards into the worm tube, so as to be a quarter of an inch above its bore) the products entered. The other extremity of the tube issues vertically near the edge of the vessel, opposite to the one where the products enter. A thermometer, having a cylindrical reservoir in length equal to the depth of the calorimeter, shows at all times the mean temperature of all the contained water. And, lastly, the whole apparatus is supported by four slight pillars of dry wood.

Now it is evident that if we burn bodies under the mouth of the circulating tube the gaseous products which result, and even the air heated by their contact, will rise into the circulating channel of the apparatus; and there, giving up the excess of their temperature above that of the surrounding water, will elevate it some degrees. In order that this operation be exact, it is essential that the combustions thus produced should be complete; this may be known by the burning body being entirely consumed, with a clear flame, without mixture of ice and water, so as to be entirely covered, all but just the extremity of the beak. This done, the spout is uncovered and lighted, and after the combustion has continued a certain time the lamp is extinguished by covering up the spout as before. But in order that the flame may not grow weak during combustion, which would render the process much more slow and imperfect, it is necessary, towards the beginning, to admit a little air to the interior by removing the stopper A, so that the liquid may not be confined by the action of the atmosphere pressing upon the orifice of the lamp. This requires that the stopper A should fit into a small tube, elevated a little above the cooling mixture. By the help of these precautions, Rumford satisfied himself that he obtained complete combustion, by this very delicate indication, that no smell was perceptible. The process completed, and the lamp closed, it is removed, well wiped, and again weighed. Thus we know the loss it has sustained, that is to say the mass of liquid consumed, and the rest of the calculation proceeds as in the former example.

In the following table are collected the values of c' for a few substances, such as they result from the experiments of Count Rumford and MM. Lavoisier and Laplace. They are expressed, according to our formula, in degrees of the centigrade scale, adopting for the unit the value of c for water.

Substances.	Rise of temperature which the combustion of 1 gramme would give to 1 gramme of water.	Remarks.
Hydrogen gas..........	23400°	L. L.
Olive oil..............	11166	L. L.
Olive oil..............	9044	R.
White wax............	10500	L. L.
White wax............	9479	R.
Linseed oil............	9307	R.
Lard..................	8369	R.
Lard..................	7186	L. L.
Sulphuric ether........	8030	R. S. G. 0.72834 at 20°.
Phosphorus............	7500	L. L.
Carbon................	7226	L. L.
Naphtha...............	7338	R. S. G. 0.82731 at 13½
Alcohol, 42° Ar.........	6195	R. S. G. 0.817624 } at 15.5
Alcohol, weaker........	5422	R. S. G. 0.84714 } at 15.5
Alcohol, 33° Ar.........	5261	R. S. G. 0.85324 } at 15.5
Oak wood............	3146	R.

L. L. MM. Lavoisier and Laplace. *R.* Count Rumford. The latter are generally the lower. May not this be because the calorimeter of ice absorbs all the heat disengaged even by radiation, while that portion is lost to all other processes?

MM. Clement and Desormes found that woods only heat in proportion to the quantity of carbon which they contain; this in all being = to half their weight, gives also nearly 3600° of heat. As Rumford obtained a less number for oak, may it not be accounted for by the loss of the radiant heat?

If we divide the numbers in this table by 100, we obtain the number of grammes of water at 0° which 1 gramme of each substance will boil by its combustion; and if we divide by 75, we obtain the number of grammes of ice at 0° which that combustion will melt.

(160.) Mr. Dalton's researches were principally directed towards the gaseous bodies. A bladder, which would hold 30000 grains of water, was filled with the gas, and fitted with a tube and stop-cock. A tin vessel, holding the same quantity of water, was provided, and its capacity for heat estimated, and then as much water added for a correction as might make the specific heat of the vessel and water together exactly equivalent to that of 30000 grains of water. The gas was suffered to issue from the bladder, and burned with its flame applied to the bottom of the vessel. The heat evolved was measured by a thermometer placed in the water. In this process some little heat would be lost by radiation, and by the currents of heated air passing the tin vessel. (*f.*)

(161.) This subject occupied the attention of Sir H. Davy also, during the course of his admirable researches on flame. A copper vessel was provided, holding olive oil previously raised to the temperature of 212° Fahrenheit, for the purpose of avoiding the possible interference of aqueous vapour condensing upon the vessel. A thermometer was placed in the oil, and the flame of the burning gas issuing from a platinum jet, connected with the gas-holder, was suffered to play upon the bottom of the copper cup containing the oil. Thus the elevation of the temperature, and the quantities of each gas consumed in a given time were known; and from the latter the quantity of oxygen gas consumed could be obtained by calculation. Upon these two data Sir Humphry calculated the relative heating power of the series of gases which he examined.

All the gases issued as nearly as possible under the same pressure, and equal intervals of time were employed for each experiment.

The following table exhibits the results:

Substances.	Rise of thermometer from 212°.	Increment of heat in degrees of Fahrenheit.	Oxygen consumed.	Ratios of heating power.
Olefiant gas…………	270°	58°	6.0	9.66
Hydrogen gas……….	238	26	1.0	26.00
Sulphuretted hydrogen ..	236	24	3.0	6.66
Coal gas ……………	232	20	4.0	6.00
Carbonic oxide……….	218	6	1.0	6.00

It is remarked, however, by Sir Humphry, that these ratios can only be considered as approximations to the truth; as there are unavoidable sources of inaccuracy in the experiments. For instance, charcoal was deposited upon the bottom of the vessel, both from coal gas and from the olefiant gas, and sulphur from the sulphuretted hydrogen. (*g*.)

It has been stated by MM. Clement and Desormes, that the different heats given out during the combustion of various woods, are in the direct ratios of the quantities of charcoal which they contain respectively.

(162.) A general tabular view of the results of Lavoisier, Crawfurd, Dalton, and Rumford, is given in the Appendix from Dr. Ure, No. IX. For Count Rumford's results, referring to different woods, we can only again mention his own very elaborate papers. (*e*.)

(163.) It is not, however, to these slight variations in the calorific effects of combustible bodies that we look for ordinary practical applications; but to the varied construction of furnaces, by which economy of fuel, or some certain convenience of its disposition for producing rapid combustion, is obtained. On these points see FURNACE, in the Article on the applications of Science to the Arts. For another very powerful source of applied heat, see the Article BLOWPIPE in the Miscellaneous Division of this Work.

(164.) Such are the means resorted to for the heating of bodies, a process of constant occurrence in the arts, and essential in producing many of the comforts of civilized life. But for experimental research it is frequently desirable to produce reduction of temperature far below that degree of cold which may be incidental to the season of the year, or to other adventitious circumstances under which the experiments may be made. Thus we are led to a description of what are called freezing mixtures, and on this head we shall principally follow the details of Dr. Murray, adding the tables of Professor Thomson, which were communicated to him by Mr. Walker.

eezing xtures. (165.) The principal ingredients of freezing mixtures are salts, many of which in dissolving in water produce considerable cold. By adding nitre to water, in as large a quantity as can be dissolved, the temperature is reduced 17 degrees; and by dissolving muriate of ammonia in the same way, 26 or 28 degrees. Nitrate of ammonia in fine powder, added to an equal weight of water, in dissolving reduces the temperature from 50° of Fahrenheit to 4°; and three parts of muriate of lime, added to two of water, sink it from 36° to — 1°. As water though saturated with one salt, will dissolve a portion of a second, and even of a third, it is possible, by adding two or more salts to water, to obtain a greater cold than from the solution of one. By this method Mr. Walker produced degrees of cold which before had not been obtained without the assistance of ice. (*i*.)

When salts are dissolved in acids more or less diluted, still more intense degrees of cold are produced, owing to the solution proceeding more rapidly. Sulphate of soda added to nitrous acid, diluted with one part of water, produces a fall of temperature from 51 to — 1, and so of many others.

It has long been known that ice or snow added to acids dissolves quickly, and during its solution produces considerable cold. This was remarked by Boyle, and by persevering in such methods, mercury was first frozen by Braun at St. Petersburg. (*k*.) According to Lowitz, when the acids are undiluted the muriatic is most effectual. (*l*.) The most powerful of these mixtures are, however, composed of snow or ice mixed with solid salts, and by these very great reductions of temperature are obtained.

"In conducting the process of artificial refrigeration, a number of circumstances require to be attended to, in some measure varied according to the kind of freezing mixture that is to be used. In obtaining cold from the solution of salts in water, or in acids, it is necessary that the salts should be fresh crystallized, neither efflorescent nor humid, and reduced to fine powder; the material ought to be quickly and thoroughly mixed; the vessel should be just large enough to contain the mixture; and the vessel in which the substance to be subjected to refrigeration is contained, ought to be of glass, and thin. In employing mixtures of snow with acids or salts, the snow should be loose, dry, and, if possible, newly fallen; the quantities of materials should be mixed at once in due proportion, and as quickly as possible. If muriate of lime be employed it should be dry and in fine powder. Lowitz and Walker both direct that it should be in that state in which it is crystallized with the largest quantity of water of crystallization, by putting its solution to cool, when of the density of 1.5 or 1.53. In cooling the materials, where this is requisite, they ought to be put into separate glass or tin vessels, placed in a freezing mixture of the requisite power; but care must be taken not to cool them beyond that point at which they act upon each other; or, in other words, near to that at which the liquid resulting from their mutual action congeals. Lastly, the due proportion of the ingredients should be observed; for any considerable excess of either, merely communicates caloric to the mixture during refrigeration and so far diminishes the effect."

The phenomenon of freezing mixtures was explained by Irvine, (*m*) on the general principle of the absorption of caloric which attends the rapid liquefaction of the materials, arising out of their chemical action; and is ultimately to be referred to the enlargement of capacity consequent on that change of form; the cold produced being greater as the capacity is more enlarged.

"Thus we may in some measure predict what substances are best fitted, by their mutual action, to produce cold; what degree of cold may be expected from their mixture in any given case; what will be the maximum of refrigeration; and what will be the best proportions of the materials to obtain that maximum.

"It is obvious that those substances will produce the greatest cold, which by mutual action produce the most rapid solution; which, during that solution, suffer the greatest augmentation of capacity; and which form a solution that at low temperatures remains liquid. There is, perhaps, no individual mixture in which all these circumstances are present to the greatest extent; yet the knowledge of them enables us to point out the respective powers of the different mixtures which are employed.

"Thus, in the solution of a salt in water, there is merely the gradual transition of the solid to the fluid form; hence, the cold produced is not considerable. When two salts are mingled together, these, by their reciprocal action, both accelerate the solution of each other, and enable a given quantity of water to dissolve a greater quantity; as more solid matter, therefore, passes to the fluid state, and passes more quickly, a greater portion of caloric is absorbed, and a greater degree of cold is produced. The attraction of acids to water, or, to state it more correctly, to the solid matter of water, is strong, and their mutual action is energetic; ice too is a substance which, in its transition to fluidity, suffers a very considerable augmentation of capacity; hence it may be concluded, what experiment proves to be just, that from the action of acids on snow or ice, a great degree of cold will arise. Lastly, in the mixture of two solid substances, which by mutual action pass to fluidity, the enlargement of capacity must be greater, and a greater diminution of capacity produced. It is so, in fact; at the same time there is a limit placed to it, from two solids acting with greater slowness than a solid and fluid do; the transition to fluidity is therefore more gradual, and the caloric not so rapidly absorbed. Hence the cold which is produced in these cases is not equal, as Blagden observed, to the cold arising from the solution of the salt in water, added to the cold that would also arise from the sudden liquefaction of the ice. This is the reason why mixtures of acids with snow or ice are often equal to the mixtures with solid salts; because, although in the latter case more matter passes to the fluid form, in the former a given quantity is liquefied more rapidly. And those salts which produce the greatest cold are those which exert the strongest attraction to water, and act on it most rapidly, as potash and muriate of lime.

"There is another principle to be attended to, which in these mixtures modifies the quantity of caloric absorbed from the liquefaction. Although the indirect consequence of the chemical action between the substances mixed is absorption of the caloric, in consequence of the liquefaction it occasions, yet its direct tendency is to evolve caloric by the increase of density which it occasions, independent of change of form. Hence two effects arise from the mutual action of the ingredients of freezing mixtures; evolution of caloric, as the result of the combination, and absorption of caloric, as the result of the liquefaction to which the combination gives rise; and the ultimate effect is compounded of these, so that the actual change of temperature is only the excess of one over the other.

"It may even happen, that the one shall exactly counterbalance the other; of this is an example in the solution of sulphate of soda in alcohol, which produces neither heat nor cold; or, it may happen, that the heat from condensation shall exceed the cold from liquefaction, as in the solution of potash in water."

The general principle now stated is exemplified in the action of acids on ice, and, as applied to this case, is clearly stated by Laplace: "If the mixture of an acid, with a given quantity of water, produce heat; in mixing that acid with the same quantity of ice, it will produce heat or cold, according as the heat which results from its mixture with water is more or less considerable than that which is necessary to melt the ice." (*n*.)

On this principle many of the facts connected with the operation of freezing mixtures are explained. Thus we perceive why concentrated sulphuric acid poured on snow or ice produces at first heat instead of cold; the action is so energetic, that the caloric evolved from the combination is superior to what is absorbed by the liquefaction. But when the acid is combined with a portion of water, its affinity being thus weakened, its action is less energetic, and less augmentation of temperature attends their union. Hence, in the progress of the experiment in which the concentrated acid is poured on snow, although heat is at first produced it is soon succeeded by cold; or if the acid has been previously diluted with a portion of water, it will, when added to the snow, immediately produce cold. Even nitric acid, as Cavendish observed, produces at first a degree of heat when added to snow; but when diluted with one-fourth of water, it immediately occasions cold. The requisite dilution is, therefore, less in nitric than it is in sulphuric acid, and it is still less in muriatic; and we perceive the reason of this,—these acids evolving less caloric when they combine with water than sulphuric acid does, and therefore counteracting less the cold from the liquefaction. And, lastly, if the dilution of the acid be carried too far, its attraction may be so much weakened, that its action on the snow will be feeble, the liquefaction will be slowly performed, and no great cold will be occasioned.

In the other kind of freezing mixtures, there can be no doubt that the same circumstance operates. The heat from combination always counteracts the cold from liquefaction; it is only the excess that prevails, and in no case is the whole reduction of temperature that would arise from the liquefaction of the quantity of matter employed, obtained. This explains the fact, that crystallized salts produce more cold than the same salts deprived of their water of crystallization; as by its presence the mutual action of the salt and the substance mixed with it is rendered less energetic, and therefore less heat is evolved from the combination; and, probably, water, in becoming liquid, suffers a greater enlargement of capacity than a salt does; which will the inaccuracy of the preceding law, and had endeavoured to substitute for it another, in which the loss of heat increased more rapidly than by the Newtonian law. Erxleben (*d*) proved equally, by very acute observation, that the deviation of the supposed law increases more and more, as we consider greater differences of temperatures; and concludes, that we should fall into very great errors, if we extended the law much beyond the temperature at which it has been verified. This very just remark of Erxleben, as well as his memoir, seems to have escaped the attention of philosophers; for in all posterior remarks on the same subject, the law of Newton has been presented, not as an approximation, but as a rigorous and constant truth. Thus Mr. Leslie, (*e*) in his ingenious researches on heat, has made this law the base of several determinations, which, from that very cause, are inaccurate, as we shall prove in the sequel.

Soon after the publication of Mr. Leslie's code, Mr. Dalton made known, in his new system of Chemical Philosophy, a series of experiments on the cooling of bodies raised to a very high temperature. The result of these experiments shows evidently that the law of Richmann is only an approximation at low temperatures, and that it is quite inaccurate at high temperatures. Mr. Dalton instead of seeking to represent his observations by a new law, endeavoured to reestablish the law of Richmann, by substituting for the usual thermometric scale the one which he founded on the notion that the dilatation of all liquids is subjected to the same law. But even supposing the accuracy of the principles of this new scale to have been established, we should be under the necessity of acknowledging, that it does not satisfy the condition of rendering the loss of heat in a body proportional to the excess of its temperature above that of the surrounding air; or, in other words, that it does not reestablish the law of Richmann; for before this could happen, it would be necessary that the law of cooling should be the same for all bodies, and our experiments prove the contrary.

The last experiments undertaken on this subject, are those which Laroche has inserted in his memoir, relative to some properties of radiant heat. He establishes, among other propositions, that the quantity of heat which a hot body gives off in a given time, by way of a radiation to a cold body situate at a distance, increases, other things being equal, in a progression more rapid than the excess of the temperature of the first above that of the second.

This proposition is evidently for radiation, the equivalent of that of Mr. Dalton for the total cooling of a body in the air; but Laroche has only presented insulated facts, and has not sought for the law on which they depend. We shall see hereafter that the results are complicated by the action of particular causes, from which it would be necessary to disengage them, in order to arrive at the law of cooling in a vacuum, which is not the same case as that of ordinary radiation.

Thus the labours of philosophers on the laws of cooling, have been hitherto confined to showing that the law of Newton is a sufficient approximation at low temperature, but that it deviates further and further from the truth as the difference between the temperature increases.

If in the concise history of these labours, we have not mentioned the mathematical researches of M. Fourier, on the laws of the distribution of heat, the reason is, that all the results of his analysis are deduced from the law of Newton, admitted as a truth founded on observation, while the sole object of our experiments is to discover the law that ought to be substituted for it. But the very remarkable consequences to which this profound mathematician has been led, will preserve all their precision in the circumstances, and within the limits in which the Newtonian law is true, and to extend them to other cases, it will be sufficient to modify them conformably to the new laws which we shall establish.

On Cooling in general.

When a body cools in a vacuum, its heat is entirely dissipated by radiation. When it is placed in air, or in any other fluid, its cooling becomes more rapid; the heat carried off by the fluid being in that case added to that which is dissipated by radiation. It is natural, therefore, to distinguish these two effects; and as they are subject in all probability to different laws, they ought to be studied separately. We shall examine then successively the laws of cooling in a vacuum and in elastic fluids.

But as the plan which we have followed in each of these researches is founded on the same principles, it will be proper to explain these principles in the first place.

The most simple case of cooling, will be that of a body of so small a size that we may suppose at every instant all its points at the same temperature. But to arrive at the object which we proposed, the discovery of the elementary law of cooling, it would have been an useless complication to the question, and would have rendered it almost incapable of solution to have observed, in the first place, the rate of cooling in solid bodies; because in that case the phenomenon includes an additional element, namely, the interior distribution of the heat, which is a function of the conductibility. Obliged by the nature of the problem to have recourse to liquids, the mercurial thermometer itself appeared to us the body best adapted for these experiments. But as it is necessary to be able in observations at high temperatures to give to the body on which the experiment is made such a size that the cooling shall not be too rapid for following its rate with accuracy, it was necessary, in the first place, to examine what influence the greater or smaller mass of liquid, contained in the bulb of the thermometer, had upon the law of cooling. It was not less important to examine whether that law depends on the nature of the liquid, or on the nature or form of the vessel in which it is contained.

These first comparisons were the object of a series of experiments which we shall state, after having explained the uniform mode of calculation which we always employed, in order to render our results more easily comparable.

Suppose we observe at given intervals of time, every minute for example, the excess of temperature of a body above the surrounding medium, and that for the times $0, 1' \; 2', 3'$, &c. . . . . t' the excesses are A, B, C, ... T.

If the law of geometrical progression held good, we should have $B = A\,m$, $C = A\,m^2$, m being a fraction which would be different for different substances. This

Excess of the temperature of the body.	Velocity of cooling of mercury.	Velocity of cooling of absolute alcohol.	Ratio of these velocities.
60°	1.89°	1.50°	0.798°
30	1.36	1.09	0.801
20	0.87	0.69	0.794

Excess of the temperature of the body.	Velocity of cooling of mercury.	Velocity of cooling of sulphuric acid.	Ratio of these velocities.
60°	3.03°	1.97°	0.650°
50	2.47	1.59	0.649
40	1.89	1.22	0.646
30	1.36	0.89	0.654

The ratios inserted in the last columns of these tables show us that the law of cooling is the same for the four liquids compared; for the small irregularities in these ratios proceed evidently from uncertainty in the observations, and, besides, to make them disappear, it would be sufficient to alter the values of the velocities observed, by quantities which scarcely amount to the hundredth of a degree.

Now if liquids so different in their nature, their density, and their fluidity, exhibit laws of cooling absolutely similar, is it not natural to draw the same conclusion to which we were already led by a comparison of the cooling of unequal masses? That, within the limits of our observations the cooling of a liquid mass is subject to the same law as a body of indefinitely small dimension. It remains now to examine the influence of the nature and shape of the vessel.

We, in the first place, compared the cooling of two spheres, the one of glass, the other of tin plate, both filled with water. (The diameter of the tin plate sphere was a little greater than that of the glass sphere.)

Excess of the temperature of the body.	Velocity of cooling of the glass sphere	Velocity of cooling of the tin plate sphere.	Ratio of these velocities.
60°	1.39°	0.90°	1.54°
50	1.13	0.73	1.55
40	0.85	0.54	1.57
30	0.62	0.38	1.63
20	0.37	0.21	1.76

Here the ratios in the fourth column vary always the same way, and show us that the law of cooling is more rapid in the tin plate sphere than in the glass sphere. Mr. Leslie obtained the same result, which he has generalized by admitting that this law changes with the nature of the body, and that it is most rapid in those bodies which radiate least. This proposition is true in the portion of the scale to which Mr. Leslie's experiments were confined; but, by a very remarkable casualty, the contrary effect takes place at high temperatures, so that when we compare the laws of cooling of two bodies with different surfaces, that of the two laws which is most rapid at the lower part of the scale becomes the least rapid at high temperatures. Thus, in the series given above, the ratios inserted in the last column diminish in proportion as we consider greater excesses of temperature; but they would again augment if we were to extend the series further; and, as is the case with all quantities which change their sign, these ratios remain nearly the same during a considerable extent of the thermometric scale. This is one of the most important points of the theory of cooling. If we do not deceive ourselves respecting the accuracy of our observations, a very simple explanation will be found in the subsequent part of this memoir of this remarkable fact, which can only be observed by making experiments, as we have done, on the cooling of bodies raised to a high temperature.

It is because they did not follow this plan that Messrs. Dalton and Leslie have obtained such inaccurate results respecting this question. The first led away, without doubt, by the notion that the law of Richmann is verified in his thermometric scale, and not having compared the cooling of different surfaces for a sufficiently large interval, has been led to suppose that the law of cooling is the same in all bodies. And Mr. Leslie, who had remarked that the law changes with the nature of the surface, not having included in his experiments temperatures sufficiently high, concluded that the difference which he observed always increases as we advance in the thermometric scale. This has led him to consequences very far from the truth, respecting which we shall have occasion to make observations in the sequel. We shall merely remark, in expressing our surprise, that Mr. Leslie, whom the influence of the nature of the body on the law of cooling did not escape, and who had concluded in consequence that the law of Richmann must be inaccurate, has nevertheless made use of this in most of his experiments. We terminate these preliminary researches by examining the cooling of water in three vessels of tin plate of the same size.

The first spherical; the second cylindrical, having a height equal to twice the diameter of its base; and the third likewise cylindrical, but having a height equal to half its diameter.

Excesses of temperature.	Velocity of cooling of the sphere.	Velocity of cooling of the first cylinder.	Velocity of cooling of the second cylinder.	Ratio of column three to column two.	Ratio of column four to column two.
60°	0.90	1.11	1.10	1.23	1.12
50	0.73	0.89	0.80	1.22	1.10
40	0.54	0.66	0.60	1.22	1.11
30	0.38	0.47	0.43	1.23	1.13
20	0.21	0.26	0.23	1.24	1.10

law never holds exactly, especially when the temperatures A, B, C, are high. But it is clear, that we may always represent a certain number of the terms by an expression of the form $A\,m^{\alpha t + \beta t^2}$, by determining properly the coefficients m, α, β, and by means of that formula, we may calculate very nearly the value of the time t, corresponding to any excess of temperature T, provided that this excess be comprehended in the portion of the series which has served for interpolation.

This same expression gives us the means of determining the rapidity of cooling corresponding to each excess of temperature; that is to say, the number of degrees which the temperature of a body would sink in a minute, supposing the rate of cooling uniform during that minute, we have, in fact, for that velocity,

$$\frac{d\,T}{d\,t} = (\log m) \,.\, T \,.\, (\alpha + 2\,\beta\,t)$$

This quantity must always exceed the real loss of temperature during the time, since the rapidity of cooling diminishes during its whole duration, how short soever it may be. It was not, as may easily be conceived, to correct the small difference of which we have just spoken that we employed this process. But it is obvious, that when a series is divided into several parts, represented each by empirical formulæ, which correspond, as exactly as possible, with the numbers observed, the velocity of cooling deduced from these formulæ for the different excesses of temperature, are always free from the uncertainties and inaccuracies which the crude results of the observations present.

Let us return now to the first comparison, of which we spoke a little ago, and for this, let us examine how the velocity of cooling has varied in the three series, the calculated results of which are contained in the following table:

Excess of temperature above the air.	Velocity of cooling of the thermometer A	Velocity of cooling of the thermometer B	Velocity of cooling of the thermometer C
100°	18.92°	8.97°	5.00°
80	14.00	6.60	3.67
60	9.58	4.56	2.52
40	5.93	2.80	1.56
20	2.75	1.30	0.73

The first column contains the excess of the temperature of the thermometers above that of the surrounding air. The second exhibits the corresponding velocities of cooling of the thermometer A, the diameter of whose bulb was about two centimetres. These velocities were calculated from the observations by the method explained above. The third and fourth columns exhibit the velocities of the cooling of the thermometers B and C, calculated in the same way for the excess of temperature indicated in the first column. The diameter of the bulb of the thermometer B was about four centimetres; that of the thermometer C about seven.

A simple inspection of this table shows us at once the inaccuracy of the law of Richmann; for we see that the velocities of cooling increase according to a more rapid progression than the excesses of temperature. Now if we take the ratios of the corresponding numbers in the second and third columns, we shall find that they have varied as follows, beginning with the terms which correspond with the greatest excess of temperature:

2.11......2.12......2.10......2.12......2.11.

These numbers, which differ very little from each other, and which are alternately greater and less, inform us that the rate of cooling follows the same law in the two thermometers A and B. If we compare in the same way the numbers contained in the second and fourth columns, we obtain for their ratios,

3.78......3.81......3.80......3.80......3.77.

The near approximation to equality in these numbers shows us that the law of cooling is likewise the same for the thermometers A and C; for the differences in the preceding numbers must be ascribed to unavoidable errors in the experiments, and they are owing to inaccuracies merely of one hundredth of a degree in the velocities. We are entitled to conclude, from what precedes, that the law of cooling observed in a mercurial thermometer is independent of the size of its bulb; and, consequently, that it is the elementary law of cooling of which we are in search, or in some measure, the law of cooling of a point.

We have not examined how the velocity of cooling varies with the extent of surface, in consequence of the little precision of measurement of which the surface of a ball of glass, blown at the extremity of a tube, is susceptible; and because that research was foreign to the object which we had in view. However, it will be seen from the approximate measures which we have in view of the diameters of the bulbs, that the velocities of cooling are nearly inversely as the diameters, as would be the case with a solid sphere of indefinitely small size.

Let us now proceed to the examination of the influence which the nature of the liquid in the vessel may have upon the law of cooling. There the difficulty of constructing thermometers with liquids different from mercury (a difficulty depending upon the uncertainty which still exists respecting the laws of dilatation of these bodies) determined us to observe the cooling of these liquids enclosed in the same glass matrass, in the centre of which was placed a very sensible mercurial thermometer. We even ascertained that the position of the thermometer is indifferent, and that at any given instant the temperature of all the points of the mass is sensibly the same. This evidently depends upon the interior conductibility, which in liquids is the result of the currents being nearly perfect, at least for masses of the size of those which we employed.

The first of the following tables contains the velocities of the cooling of mercury and water compared; the second exhibits a similar comparison between mercury and absolute alcohol; and the third between mercury and concentrated sulphuric acid.

Excess of the temperature of the body.	Velocity of cooling of mercury.	Velocity of cooling of water.	Ratio of these velocities.
60°	3.03°	1.39°	0.458°
50	2.47	1.13	0.452
40	1.89	0.85	0.450
30	1.36	0.62	0.456

remained in the balloon. The stop-cock was then and the observations commenced. When the iment was to be conducted in air, that of the on was at first dilated, in order to facilitate the ct of surfaces, and then the proper quantity was ed to enter. When the cooling was to be observed gas, the balloon was first emptied of air, gas was allowed to enter, and a vacuum was again made; which the requisite quantity of gas was introduced. is contrivance it was mixed with only an inappre- quantity of air.

shall terminate this description by saying, that mensions of the thermometer had been calculated at the observation of the cooling could begin at 300°. The experiments in air and in the gases re rather a long preparation, and cannot be com- ed with safety till the equilibrium is restored gh the whole extent of fluid. The series of obser- is belonging to them commence at about 250°.

e experiment for cooling in vacuo, or in gases, thus prepared, it remained merely to observe the of cooling by means of a watch with a second's at equal intervals of time. But these temperatures e two corrections, which we shall point out. In rst place, it is obvious, from the nature of our atus, that after a short time the stem of the ther- ter was cooled down to the temperature of the nding air. Every temperature observed, there- was too low by a number of degrees equal to that to the mercury in the stem would dilate, when heated the temperature of the surrounding atmosphere to f the bulb. This correction was easily calculated, as applied to all the temperatures observed. The of the second correction was to reduce the indi- is of the mercurial thermometer to that of the air ometer; for this we employed the table given in 7.

ving thus obtained a series of consecutive tempe- s of the thermometer, it only remained to apply t series the mode of calculation which we have ned above. We divide it then into two parts, were represented each by expressions of the $m^{\alpha t + \beta t^2}$ in which t denotes the time; and formulæ served to calculate the velocity of cooling e different excesses of temperature; but these ties required a diminution easily determined in case. That it may be conceived in what this ts, we must remark, that the cooling of the bulb thermometer, arising from the loss of heat which place at the surface, is always a little augmented entrance of cold mercury from the stem of the meter. But the volume of mercury being known, ewise its temperature, it was easy to estimate the amount of this correction, which, though all, ought not to have been neglected.

is the mode which we always followed in con- all our experiments. We satisfied ourselves ermining the velocity of cooling for excesses of ure differing from each other by 20 degrees. we might not make this memoir too tedious, withheld all the intermediate calculations to our determinations.

ll now enter upon a detail of our experiments; m in the order in which they were made.

iminary researches having made us acquainted fluence of the nature of the surface upon the ing, it was necessary to study that law under different states of the surface of our thermometer. But it was necessary, likewise, that these surfaces should not experience any alteration from the highest temperatures to which they should be exposed. The only two which appeared to us to answer this condition, are surfaces of glass and silver. Accordingly most of our experiments were made, first preserving to the thermometer its natural surface, and then covering it with a very thin leaf of silver. These two surfaces possess, as is known, very different radiating powers, glass being one of the bodies which radiate most, and silver of those which radiate least. The laws to which we have arrived, by comparing the cooling of these two surfaces, are of such simplicity, that there can be no doubt of their being applicable to all other bodies.

On Cooling in a Vacuum.

The observations on the cooling in vacuo, calculated as before explained, are all affected by an error, very small indeed, but which it is easy to correct. This error arises from the small quantity of air remaining in the balloon, and which, in the greater number of experiments, amounted only to two millimetres. This correction cannot be applied immediately to the series temperatures furnished by observation; but it can be easily applied to the velocities of cooling obtained by calculation. It is merely necessary to diminish them by a quantity corresponding to the heat carried off by the air remaining in the balloon.

To determine the amount of this correction in each case, we observed the cooling of our thermometer in air of different degrees of density; and we calculated for the different excesses of temperature, the velocities of cooling corresponding to each density. By subtracting from these velocities those which take place in vacuo, we obtain exactly the quantities of heat caused by the air in its different states of rarefaction. We shall have nearly accurate values of these same quantities, by subtracting the velocities already very near each other, which are given by the observations of cooling in the balloon, when it contains only a very small quantity of gas.

Having thus determined for each excess of temperature, and for different densities, the quantities of heat carried off by the air, we observed that they followed a simple law, by means of which we determined, with sufficient precision, the corrections which calculated velocities ought to undergo.

The numbers, therefore, which we shall give in the subsequent part of this Chapter, may be considered as differing exceedingly little from those which would be obtained by making the experiments in an absolute vacuum. Let us now proceed to the examination of the different series calculated and corrected, and let us begin with that in which the balloon was surrounded by melting ice. The thermometer preserved its natural vitreous surface.

Excess of the thermometer above the balloon.	Corresponding velocities of cooling.
240°	10.69°
220	8.81
200	7.40
180	6.10
160	4.89
140	3.88
120	3.02
100	2.30
80	1.74

The first column contains the excesses of temperature of the thermometer above the sides of the balloon, that is to say, the temperatures themselves, since the balloon was at 0°. The second column contains the corresponding velocities of cooling, calculated and corrected by the methods already pointed out. These velocities, as we have already frequently observed, are the number of degrees that the thermometer would sink in a minute, supposing the cooling uniform during the whole minute. The first series shows clearly the inaccuracy of the law of Richmann; for, according to that law, the velocity of cooling at 200° should be double that at 100; whereas we find it more than triple. When we compare, in like manner, the loss of heat at 240° and at 80°, we find the first about six times greater than the last, while, according to the law of Richmann, it ought to be merely triple.

Nothing would be easier than by a formula composed of two or three terms to represent the results contained in the preceding table, and to obtain in this way an empirical relation between the temperature of bodies and the corresponding velocities of cooling. But formulæ of this kind, though without doubt they are useful when we wish to interpolate, are almost always inaccurate beyond the limits within which the observations have been made, and never contribute to make us acquainted with the laws of the phenomena which we study.

We have thought it necessary, therefore, before endeavouring to find any law, to vary our observations as much as the nature of the subject would admit; and we have been guided in this by a remark relative to the theory of radiation, which we think has not hitherto been made by any philosopher.

In the theory of the exchanges of heat which has been adopted, the cooling of a body in vacuo is merely the excess of its radiation above that of the surrounding bodies. Therefore if we call θ the temperature of the substance surrounding the vacuum in which the body cools, and $t + \theta$ the temperature of the body, we shall have in general for the velocity, V, of cooling, (observing that this velocity is nothing when t is nothing.)

$$V = F(t + \theta) - F(\theta)$$

F denoting the unknown function of the absolute temperature which represents the law of radiation.

If the functions $F(t + \theta)$ and $F(\theta)$ were proportional to their variables; that is to say, if they were of this form, $m(t + \theta)$ and $m(\theta)$; m being a constant quantity, we should find the velocity of cooling equal to $m\,t$, and we should fall into the law of Richmann; since the velocity of cooling would be proportional to the excesses of temperature. These velocities would be at the same time independent of the absolute temperatures, as has been hitherto supposed. But if the function, F, be not proportionable to its variable, as our experiments prove, the expression

$$F(t + \theta) - F(\theta)$$

which represents the velocity of cooling, ought to depend at once upon the excess of temperature t, and the absolute temperature θ of the surrounding medium. It was to verify this consequence, that we observed the cooling of the thermometer in vacuo, raising successively the water surrounding the balloon to 20°, 40°, 60°, 80°. The following table presents, at one view, all the results of each of these series of observations, which were repeated several times.

Excess of temperature of the thermometer.	Velocity of cooling water at 0°.	Velocity of cooling water at 20°	Velocity of cooling water at 40°	Velocity of cooling water at 60°	Velocity of cooling water at 80°
240°	10.69°	12.40°	14.35°	—	—
220	8.81	10.41	11.98	—	—
200	7.40	8.58	10.01	11.64°	13.45°
180	6.10	7.04	8.20	9.55	11.05
160	4.89	5.67	6.61	7.68	8.95
140	3.88	4.57	5.32	6.14	7.19
120	3.02	3.56	4.15	4.84	5.64
100	2.30	2.74	3.16	3.68	4.29
80	1.74	1.99	2.30	2.73	3.18
60	—	1.40	1.62	1.88	2.17

This table, which requires no explanation, confirms, as is evident, the principle which we have established; but the results which it contains lead us to a very simple approximation, which discovers the law of cooling in vacuo. If we compare the corresponding numbers of the second and third columns, that is to say, the velocities of the cooling for the same excess of temperature, the surrounding medium being successively at 0° and at 20°, we find that the ratios of these velocities were as follows:

1.16 .. 1.18 .. 1.16 .. 1.15 .. 1.16 .. 1.17 .. 1.17 .. 1.18 .. 1.15.

These numbers, which differ very little from each other without showing any regularity in their variations, only require to be made equal by changes in the observed velocities, which would scarcely amount to one per cent.

Let us now compare the velocities observed when the surrounding medium was at 20° and 40°. We shall find for the ratio of these velocities,

1.16 .. 1.15 .. 1.16 .. 1.16 .. 1.17 .. 1.16 .. 1.17 .. 1.15 .. 1.16 .. 1.16.

When the surrounding medium is at 40° and 60°, the ratios are,

1.15 .. 1.16 .. 1.16 .. 1.15 .. 1.17 .. 1.16 .. 1.18 .. 1.16.

When the surrounding medium is at 60° and 80°, the ratios are,

1.15 .. 1.15 .. 1.16 .. 1.17 .. 1.16 .. 1.17 .. 1.17 .. 1.15.

These three last comparisons lead us to the same conclusion as the first, and inform us, besides, that the constant ratio between two consecutive series, has remained always the same when the surrounding medium was heated from 0° to 20°, from 20° to 40°, from 40° to 60°, and from 60° to 80°. The preceding experiments then prove the following law.

The velocity of cooling of a thermometer in vacuo, for a constant excess of temperature increases in a geometrical progression, when the temperature of the surrounding medium increases in an arithmetical progression. The ratio of this geometrical progression is the same, whatever be the excess of temperature considered.

The first law, which applies solely to the variation of temperature of the surrounding medium, enables us to put the expression found formerly of the velocity of cooling in vacuo,

$$F(t+\theta) - F(\theta)$$

under the form

$$\phi\, t \times a^{\theta}$$

a being a constant quantity, and $\phi\,(t)$ a function of the variable t only, and which we must endeavour to discover.

The two expressions of the velocity of cooling being equal, we have

$$\frac{F(t+\theta) - F(\theta)}{a^{\theta}} = \phi\,(t)$$

Whence, by expanding into a series,

$$\phi\,(t) = t\,\frac{F'(\theta)}{a^{\theta}} + \frac{t^2}{2}\cdot\frac{F''(\theta)}{a^{\theta}} + \frac{t^3}{2.3}\cdot\frac{F'''.(\theta)}{a^{\theta}}$$

And as this equation must hold good for all values of t, we must have

$$F'\,\theta = n\,.\,a^{\theta}$$

n being an indeterminate number; whence we deduce,

$$F(\theta) = m\,.\,a^{\theta} + \text{a constant quantity,}$$

making, for the sake of shortness, $\frac{n}{\log.\,a} = m$, we get

$$F(t+\theta) = m\,.\,a^{t+\theta} + \text{a constant quantity.}$$

We have then, finally, for the value of the velocity

$$V = m\,.\,a^{\theta}\,(a^{t} - 1)$$

an equation which contains the law of cooling in vacuo.

If we suppose θ constant, the coefficient $m\,a^{\theta}$ will be so likewise, and the preceding law may be expressed. When a body cools in vacuo, surrounded by a medium whose temperature is constant, the velocity of cooling for excesses of temperature in arithmetical progression increases as the terms of a geometrical progression, diminished by some constant quantity. The ratio a of this progression is easily found for the thermometer whose cooling we have observed; for when θ augments by 20°, t remaining the same, the velocity of cooling is then multiplied by 1.165, the mean of all the ratios determined above. We have then,

$$a = \sqrt[20]{1.165} = 1.0077$$

It only remains, in order to verify the accuracy of this law, to compare it with the different series contained in the table inserted above. Let us begin with that in which the surrounding medium was at 0°. We find in this case that it is necessary to make $m = 2.037$; we have then for this case,

$$V = 2.037\,(a^{t} - 1)$$

in which $a = 1.0077$.

Excess of temperature, or values of t.	Values of V observed.	Values of V calculated.
240°	10.69°	10.68°
220	8.81	8.89
200	7.40	7.34
180	6.10	6.03
160	4.89	4.87
140	3.88	3.89
120	3.02	3.05
100	2.30	2.33
80	1.74	1.72

Let us now take the series obtained when the surrounding medium was at 20°, the preceding coefficient of $(a^{t} - 1)$ must then be multiplied by $a^{20} = 1.165$, we have then $V = 2.374\,(a^{t} - 1.)$

Excess of temperature, or values of t.	Values of V observed.	Values of V calculated.
240°	12.40°	12.46°
220	10.41	10.36
200	8.58	8.56
180	7.04	7.01
160	5.67	5.68
140	4.57	4.54
120	3.56	3.56
100	2.74	2.72
80	1.99	2.00
60	1.40	1.38
40	0.86	0.85
20	0.39	0.39

Let us proceed to the series obtained when the surrounding medium was at 40°, the preceding coefficient of $(a^{t} - 1)$ must still be multiplied by $a^{20} = 1.165$. Hence $V = 2.766\,(a^{t} - 1.)$

Excess of temperature, or values of t.	Values of V observed.	Values of V calculated.
240°	14.35°	14.44°
220	11.98	12.06
200	10.01	9.97
180	8.20	8.17
160	6.61	6.62
140	5.32	5.29
120	4.15	4.14
100	3.16	3.17
80	2.30	2.33
60	1.62	1.61

For the series in which the surrounding medium is 60°, we shall have $V\ 3.222\,(a^{t} - 1.)$

Excess of temperature, or values of t.	Values of V observed.	Values of V calculated.
200°	11.64°	11.61°
180	9.55	9.52
160	7.68	7.71
140	6.14	6.16
120	4.84	4.82
100	3.68	3.69
80	2.73	2.71
60	1.88	1.87

Lastly, when the surrounding medium is 80°, we have $V = 3.754\,(a^{t} - 1.)$

Excess of temperature, or values of t.	Values of V observed.	Values of V calculated.
200°	13.45°	13.52°
180	11.05	11.09
160	8.95	8.98
140	7.19	7.18
120	5.64	5.61

quantities of heat, taken to a temperature infinitely low, may, notwithstanding, have a finite value.

The law of cooling such as we have represented it, and such as it may be represented in vacuo, applies solely to the velocities of cooling, estimated by the diminutions of temperature indicated by an air thermometer. We may see by the correspondence of all the thermometrical scales, that if we make use of any other thermometer, the relations between the temperatures and velocities of cooling would lose that character of simplicity and generality which we have found them to possess, and which is the usual attribute of the laws of nature. If the capacities of bodies for heat were constant when we determine them by the same thermometer, the preceding law would still give the expression of the quantities of heat lost, in some function of the corresponding temperatures; but as we have proved that the specific heat of bodies is not constant in any thermometrical scale, we see that in order to arrive at these real losses of heat we must admit an additional element; namely, the variation of the capacity of the bodies subjected to observation. In considering the question under this point of view it would be necessary to know, in the first place, the law of the capacities for a certain body, and then to determine by direct observations, the quantities of heat lost by the same body at certain fixed points of temperature indicated by the air thermometer. Then, by multiplying the velocities of cooling deduced from the preceding law by the corresponding capacities, we should obtain the absolute losses of heat. It is not in the interval of the first two or three hundred degrees of the Centigrade scale that we can hope to verify the accuracy of these conclusions. The variation of the capacities not beginning to become very sensible till we pass that term, it would be necessary to observe at temperatures of 500 or 600°. It is easy to see the difficulty of such observations. However, we have succeeded in constructing an apparatus fit for the purpose; and we have already made a great many observations relative to this subject. But as our results do not yet present all the regularity which we expect to be able to give them, we have determined to delay their publication, and so much the more willingly, that the question which it is their object to answer, does not come within the limits of the prize proposed by the Academy. The method which Mr. Leslie employed for measuring the radiating powers of different surfaces, is very good for making us acquainted with the radiating heat lost by a body at all temperatures. It is well known that his method consists in estimating the radiation of a body by the heat communicated to an air or mercurial thermometer placed at a certain distance from the hot body; and to render the effects more sensible, this thermometer is placed at the focus of the reflector.

It was by means of this apparatus that Laroche obtained the result which we have mentioned above. Among the series of observations made by this method, there is one which extends, indeed, to very high temperatures; but it cannot be of any utility, because the temperatures were determined by a process founded on the supposition that the capacities were constant. The numbers which represent the losses of heat are, besides, affected by another error, proceeding from the heat of the focal thermometer being too great, because the inaccuracy of the Newtonian law had already become very sensible. But to show that our law agrees with the observations made by this process when they are freed from the causes of error of which we have just spoken, we shall apply them to the series given in the same memoir, which do not go beyond the limits in which the variation of capacity produces no sensible effect. These series belong to the radiation of an iron crucible filled with mercury; here the temperature of the body not having exceeded 200°, we may suppose the specific heat constant. We may likewise neglect the correction which the mercurial thermometer would require to bring it to the air thermometer; because this correction is very small, and because it is probable that it is more than compensated from the stem of the thermometer employed by Laroche not being completely plunged into mercury. Instead of taking each of the series which is given by this philosopher, we have taken in some measure the mean of them, assisted by a formula by which M. Biot has represented these observations, a formula inserted in p. 634, of the IVth Volume of his *Traité de Physique*. The numbers which we give as the result of observation are then deduced from the formula of M. Biot. To represent them by means of our law, we must make V, which here represents the radiation, equal to

$$4.24\ (a^t - 1)$$

t being the excess of the temperature of the crucible, and A a constant quantity, which we have found precisely equal to 1.0077.

Values of t.	Values of V observed.	Value of V calculated.
200°	15.33°	15.29°
180	12.51	12.52
160	10.09	10.15
140	8.04	8.11
120	6.30	6.36
100	4.84	4.86
80	3.60	3.58
60	2.54	2.47

This last series furnishes by its agreement with our law a new proof that the number a depends neither upon the mass nor upon the state of the surface of the body, since we find it here to have the same value as in our experiments on cooling vitreous and silvered surfaces in vacuo.

From the expression for the velocity of cooling in vacuo we can easily deduce the relation which connects the temperatures and the times. If we denote the time by x, we have

$$V = -\frac{d\,t}{d\,x} = M\ (a^t - 1)$$

M being a constant coefficient, which depends solely on the temperature of the surrounding medium: from this we have

$$d\,x = \frac{-\,d\,t}{M\ (a^t - 1)}$$

and

$$x = \frac{1}{M\,.\log a.}\left(\log \frac{a^t - 1}{a^t}\right) + \text{a constant quantity.}$$

The arbitrary constant quantity and the number M will be determined in each particular case, when we have observed the values of t corresponding to two known values of the time x.

If we supposed t so small that considering the smallness of the logarithm of a, we might confine ourselves to the terms of the first power in the developement of a^t, we should fall again into the Newtonian law.

The principle which we have just established being fully verified, we may confine ourselves in the remainder of our experiment to observe the cooling of the thermometer with the bulb naked in air and in the different gases. Henceforth we shall give only in our tables the effect produced solely by the contact of the gas. They have been always calculated, as we have said before, by subtracting from the total velocities of cooling those which would take in the same circumstances if the thermometer were cooling in vacuo. We shall now enter into the examination of the different circumstances which may modify the action of the elastic fluids in the production of the phenomenon which occupies our attention. We shall study the influence of each of these causes, first in air, then in hydrogen, carbonic acid, and olefiant gases. We made choice of the first two, in consequence of the great difference of their physical properties. Air and olefiant gas, on the contrary, offer the curious comparison of two gases of almost the same specific gravity, but of very different composition. The example of the influence of the temperature of the surrounding medium has upon the rate of cooling in vacuo, naturally led us in the first place to examine, if the temperature of the gases does not produce analogous effects upon the quantity of heat which they carry off. It is needless to say that such experiments had not yet been attempted, the philosophers who have turned their attention to this subject having always supposed that the velocities of cooling depend only on the excess of temperature. Without stopping to detail our first attempts, we shall state immediately those tables in which the law shows itself manifestly. In the experiments in question, the temperature of the gases was varied by heating sufficiently the water of the balloon; but the gas was at the same time allowed to dilate itself, so that it always preserved the same elasticity. The following table contains the results of such a set of experiments made upon air:

Excess of the thermometer above the surrounding air.	Velocities of cooling due to the contact of air under the pressure 0.72 m. temp. 20°.	Velocities of cooling due to the contact of air under the pressure 0.72 m. temp. 40°.	Velocities of cooling due to the contact of air under the pressure 0.72 m. temp. 60°.	Velocities of cooling due to the contact of air under the pressure 0.72 m. temp. 80°.
200°	5.48°	5.46°		
180	4.75	4.70	4.79°	
160	4.17	4.16	4.20	4.13°
140	3.51	3.55	3.55	3.49
120	2.90	2.93	2.94	2.88
100	2.27	2.28	2.24	2.25
80	1.77	1.73	1.71	1.78
60	1.23	1.19	1.18	1.20

The mere inspection of this table is sufficient to show us that the velocities of cooling have remained the same in each of the four series for the same excess of temperature. This simple law was of too great importance not to endeavour to verify it with other gases. The following table exhibits a similar comparison for hydrogen gas heated successively to 20°, 40°, 60°, and 80°. The elasticity in each experiment was 0.72 metre.

Excess of temperature of thermometer above the surrounding gas.	Velocities of cooling due to the contact of the gas at 20°.	Velocities of cooling due to the contact of the gas at 40°.	Velocities of cooling due to the contact of the gas at 60°.	Velocities of cooling due to the contact of the gas at 80°.
160°	14.26°	14.08°	14.18°	
140	12.11	12.16	12.12	12.08°
120	10.10	10.13	10.20	10.19
100	7.98	7.83	8.03	8.05
80	6.06	5.97	6.10	6.00
60	4.21	4.17	4.18	4.20

This table leads to the same consequences as the preceding. To show that it extends to all the gases whatever be their nature or density, we shall add here a similar set of experiments on carbonic acid, under a pressure of 0.72 metre, and on dilated air under a pressure of 0.36 metre.

Excess of temperature.	Velocities of cooling due to the carbonic acid, temperature 20°.	Velocities of cooling due to the carbonic acid, temperature 40°.	Velocities of cooling due to the carbonic acid, temperature 60°.	Velocities of cooling due to the carbonic acid, temperature 80°.
200°	5.25°	5.17°		
180	4.57	4.63	4.52°	
160	4.04	4.06	3.97	4.10°
140	3.39	3.39	3.34	3.43
120	2.82	2.80	2.79	2.83
100	2.22	2.18	2.21	2.20

Excess of temperature.	Velocities of cooling due to dilated air, temperature 20°.	Velocities of cooling due to dilated air, temperature 40°.	Velocities of cooling due to dilated air, temperature 60°.	Velocities of cooling due to dilated air, temperature 80°.
200°	4.01°	4.10°		
180	3.52	3.50	3.55°	
160	3.03	2.99	3.04	3.09°
140	2.62	2.57	2.62	2.66
120	2.12	2.16	2.14	2.15
100	1.69	1.71	1.67	1.73

From all these comparisons we may deduce the following law:

The velocity of cooling of a body, owing to the sole contact of a gas, depends (for the same excess of temperature) on the density and temperature of the fluid; but this dependence is such that the velocity of cooling remains the same, if the density and the temperature of the gas change in such a way that the elasticity remains constant.

Hence in experiments on cooling by the gases we need only attend to their elasticity. It is, therefore, the influence of this last element that we must endeavour to appreciate.

With this view we have determined for each gas different elasticities, the velocities of cooling for same excesses of temperature. Of each of these se of experiments we shall merely give what is neces to demonstrate the law which we have obtained. us begin with air.

The following table exhibits the corresponding v cities of cooling, owing to the sole contact of air u the following pressures: 0.72 m., 0.36 m., 0.18 0.09 m., 0.045 m., that is to say under press decreasing as the numbers 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$.

Excess of temperature above the air.	Velocity of cooling, pressure 0.72 m.	Velocity of cooling, pressure 0.36 m.	Velocity of cooling, pressure 0.18 m.	Velocity of cooling, pressure 0.09 m.	Velocity of cooling, pressure 0.045 m.
200°	5.48°	4.01°	2.95°	2.20°	1.59°
180	4.75	3.52	2.61	1.90	1.37
160	4.17	3.03	2.21	1.62	1.20
140	3.51	2.62	1.91	1.40	1.02
120	2.90	2.12	1.57	1.15	0.84
100	2.27	1.69	1.23	0.90	0.65
80	1.77	1.29	0.96	0.70	0.52
60	1.23	0.90	0.65	0.48	0.35
40	0.75				
20	0.32				

If we take the ratio of the corresponding numbers in the second and third columns, we find their values commencing with the uppermost as follows:

1.37. . 1.35. . 1.37. . 1.34. . 1.37. . 1.34. . 1.37. . 1.36.

We have likewise for the ratios of the numbers in the third and fourth columns

1.36. . 1.35. . 1.37. . 1.37. . 1.35. . 1.37. . 1.34. . 1.37.

The ratios between the fourth and fifth colu are

1.34. . 1.37. . 1.36. . 1.36. . 1.37. . 1.36. . 1.37. . 1.3

And, lastly, the ratios between the fifth and s columns are

1.38. . 1.38. . 1.35. . 1.37. . 1.36. . 1.37. . 1.35. . 1.3

The small irregularities which these correspon ratios present in the numbers which represent them, being less than the uncertainty of the observations, we have a right to draw from them the following conclusions:

1. *The law, according to which the velocity of cooling by the contact of air varies with the excess of temperature, continues the same, whatever the elasticity of the air is.*

2. *The elasticity of the air, varying in a geometrical progression, its cooling power changes likewise in a geometrical progression, in such a manner that when the ratio of the first geometrical progression is 2, that of the second is 1.366, the mean of all the numbers given above.* It will be easily seen that the law just announced was not recognised till we had made many experiments. But when once verified for air, it was natural to try it on the other gases. We shall now give a tabular view of the observations relative to each of these.

Let us begin with hydrogen.

Excess of temperature of the thermometer above the gas.	Velocity of cooling due to the contact of hydrogen, pressure 0.72 m.	Velocity of cooling due to the contact of hydrogen, pressure 0.36 m.	Velocity of cooling due to the contact of hydrogen, pressure 0.18 m.	Velocity of cooling due to the contact of hydrogen, pressure 0.09 m.	Velocity of cooling due to the contact of hydrogen, pressure 0.045 m.
180°	16.59°	12.86°	9.82°	7.49°	5.81°
160	14.26	10.97	8.37	6.49	4.95
140	12.11	9.24	7.11	5.47	4.24
120	10.10	7.83	5.99	4.64	3.51
100	7.98	6.23	4.72	3.63	2.80
80	6.06	4.62	3.58	2.77	2.09
60	4.21	3.21	2.48	1.88	1.46

The ratios between the numbers in the second and third columns are

1.29..1.30..1.31..1.29..1.28..1.31..1.31.

The ratios between the numbers of the third and fourth columns are

1.31..1.31..1.30..1.31..1.32..1.29..1.29.

The ratios between the numbers of the fourth and fifth columns are

1.31..1.29..1.30..1.29..1.30..1.29..1.32.

The ratios between the fifth and sixth columns are

1.29..1.31..1.29..1.32..1.30..1.32..1.29.

The very near approach to equality in these numbers furnishes us with a result analogous to that which refers to air.

Hence, 1. *The law, according to which the velocity of cooling due to the sole contact of hydrogen varies with the excesses of temperature, is the same, whatever be the elasticity of the gas.*

2. *The cooling power of hydrogen decreases in a geometrical progression, whose ratio is 1.301, when its elasticity diminishes in a geometrical progression, whose ratio is 2.*

We obtained the same results for carbonic acid and olefiant gas. This may be easily verified in the two following tables, arranged for each of these gases as the tables given above for air and hydrogen.

Excess of the temperature of the thermometer above the gas.	Velocities of cooling due to carbonic acid, pressure 0.72 m.	Velocities of cooling due to carbonic acid, pressure 0.36 m.	Velocities of cooling due to carbonic acid, pressure 0.18 m.	Velocities of cooling due to carbonic acid, pressure 0.09 m.	Velocities of cooling due to carbonic acid, pressure 0.045 m.
200°	5.25°	3.64°	2.56°	1.79°	1.25°
180	4.57	3.22	2.25	1.56	1.09
160	4.04	2.80	1.97	1.37	0.95
140	3.39	2.38	1.65	1.17	0.80
120	2.82	1.97	1.36	0.95	0.67
100	2.22	1.55	1.08	0.76	0.52
80	1.69	1.17	0.82	0.57	0.40
60	1.18	0.82	0.57	0.40	0.28

Excess of temperature of the thermometer above the gas, (olefiant.)	Velocities of cooling due to the contact of olefiant gas, pressure 0.72 m.	Velocities of cooling due to the contact of olefiant gas, pressure 0.36 m.	Velocities of cooling due to the contact of olefiant gas, pressure 0.18 m.	Velocities of cooling due to the contact of olefiant gas, pressure 0.09 m.	Velocities of cooling due to the contact of olefiant gas, pressure 0.045 m.
200°	7.41°	5.18°	3.64°	2.58°	1.84°
180	6.45	4.57	3.17	2.22	1.59
160	5.41	3.86	2.72	1.89	1.34
140	4.70	3.31	2.35	1.63	1.18
120	3.84	2.76	1.92	1.35	0.96
100	3.12	2.21	1.55	1.08	0.78
80	2.34	1.62	1.15	0.79	0.62

temperature likewise increase in a geometrical progression. The ratio of this last progression being 2, that of the first is 2.35. We deduce, likewise, by a calculation similar to those formerly employed, that the losses of heat due to the contact of a gas are proportional to the excesses of temperature of the body elevated to the power 1.233.

To enable the reader to judge of the accuracy of this law, we shall give in the following table the velocities of cooling produced by the contact of air under a pressure of 0.72 m.; the second column containing the values of these velocities observed; and the third, their values deduced from the laws which we have announced.

Excess of temperature.	Velocities observed.	Velocities calculated.
200°	5.48°	5.45°
180	4.75	4.78
160	4.17	4.14
140	3.51	3.51
120	2.90	2.91
100	2.27	2.31
80	1.77	1.76
60	1.23	1.24
40	0.77	0.75
20	0.33	0.32

It is needless to transcribe the similar comparison which we have made on the other gases, and each of the pressures under which we have operated, for we have recognised above, that the series relative to each of them follow exactly the same law as for air, and that this law is observed under all pressures. But the comparisons of which we speak, have afforded us as satisfactory results as the preceding, and indeed this may easily be verified upon each of the series of observations which we have given above. To obtain a general expression for the velocity of cooling, due to the contact of a fluid, it is necessary to collect all the particular laws which we have made known. But the first law informs us, that the state of the surface of the body has no influence on the quantity of heat which the fluid carries off from it; and the second law proves that the density and the temperature of this fluid do not affect the cooling, but in as far as they contribute to vary the pressure; so that the cooling power of the fluid depends ultimately upon its elasticity. This elasticity, and the excess of temperature of the body, are then the two only elements which can make the velocity of cooling vary. Denoting the first of these elements by p, and the second by t, we shall have for V the velocity by contact of a fluid,

$$V = m \, . \, p^c \, . \, t^b$$

b being for all gases and all bodies equal to 1.233; c being likewise the same for all bodies, but varying from one gas to another; and m having a value which changes with the nature of the gas, and with the dimensions of the body: the values of c are, as we have found, 0.45 for air, 0.38 for hydrogen, 0.517 for carbonic acid, and 0.501 for olefiant gas. The values of m depend, as we have said, on the dimensions of the body, and the nature of the gas. For our thermometer m is equal to 0.00919 in air, to 0.3318 in hydrogen, to 0.00887 in carbonic acid, and to 0.01227 in olefiant gas. (These values of m suppose p expressed in metres, and t in centigrade degrees.) We may by the preceding value of V calculate the ratios of the cooling powers of the different gases for each pressure. Thus, taking the cooling power of air at unity, and supposing the pressure = 0.76 m., we have for the cooling power of hydrogen 3.45, and for that of carbonic acid 0.965. These numbers will change with the elasticity belonging to the three gases. This Messrs. Leslie and Dalton did not perceive; but it is easily deduced from our formula. However, their determinations differ but little from those which we have calculated for the pressure of 0.76 m. We should deduce, likewise, ratios very little different from these from the experiments made more recently by Sir Humphrey Davy.

The simplicity of the general law which we have just made known, made us eagerly desire to be able to verify it at temperatures more elevated than those which we had attempted in our experiments. We succeeded by a very simple process, the idea of which was first suggested by Mr. Leslie. When our thermometer with the naked ball cooled in the open air, the total velocity of this cooling is the sum of the velocities due separately to the contact of air and to radiation. Denoting these by v and v', the total velocity is $v + v'$. If the thermometer be covered with silver, the velocity v due to the air remains the same for the same temperature, and v' is reduced to $\frac{v'}{5.707}$, since the constant ratio of the radiating powers of glass and silver is 5.707. The total cooling of the silvered thermometer is then $v + \frac{v'}{5.707}$. Hence it is easy to conclude, that in order to know at all temperatures the losses of heat produced by the contact of air, it is sufficient to determine the total velocities of cooling of our thermometer, first when the bulb is naked, and again when it is covered with silver. These velocities being represented by a and b we shall have,

$$a = v + v' \qquad b = v + \frac{v'}{5.707}$$

Hence,

$$v = \frac{5.707 \times b - a}{4.707}$$

Let us apply this formula to the results contained in the following table:

Excess of temperature of thermometer.	Total velocities of cooling of the naked bulb.	Total velocities of cooling of the silvered bulb.	Values of v.
260°	24.42°	10.96°	8.10°
240	21.12	9.82	7.41
220	17.92	8.59	6.61
200	15.30	7.57	5.92
180	13.04	6.57	5.19
160	10.70	5.59	4.50
140	8.75	4.61	3.73
120	6.82	3.80	3.11
100	5.57	3.06	2.53
80	1.15	2.32	1.93

The second and third columns contain the total velocities of cooling of a thermometer with a naked and a silvered bulb, for the excesses of temperature contained in the first column. The last column contains the corresponding values of v, that is to say, the losses of heat which the contact of air alone produces in both thermometers. But the law which these losses of heat follow, is expressed by the following equation:

$$v = m\, t^{1.233}$$

in which m must be determined in each particular case. For the one which we are considering $m = 0.00857$. By giving successively to t all the values for every 20°, from 80° to 260°, we shall have the corresponding values of v, which will differ but little from those deduced experimentally; to make this comparison more easy, we have united in the following table the observed and calculated values of v.

Excesses of temperature.	Observed values of v.	Calculated values of v.
260°	810°	814°
240	741	738
220	661	663
200	592	587
180	519	517
160	450	447
140	373	379
120	311	314
100	253	250
80	193	190

Thus, the law of the losses of heat by air is confirmed when we extend our observations to greater excesses of temperature. The results already stated will, likewise, furnish us with the means of verifying the law of cooling in vacuo. It is sufficient for that, to subtract from the total velocities of cooling those which are due to the sole contact of air, that is to say, the successive values of v. The remainder will evidently be the velocities of cooling, owing to radiation, or, which comes to the same thing, those which would have taken place in vacuo.

We give here the numbers thus determined for the thermometer with its bulb naked, we join to them the velocities deduced from the law of cooling in vacuo. The velocity in this case is expressed by

$$m\,(a^t - 1)$$

t representing the excess of temperature of the body, m a constant coefficient, which must be determined in each case, and which is here equal to 2.61; a denoting the exponent 1.0077 common to all bodies.

Excesses of temperature.	Velocities of cooling in vacuo deduced from observations in air.	Velocities of cooling in vacuo by calculation.
260°	16.32°	16.40°
240	13.71	13.71
220	11.31	11.40
200	9.38	9.42
180	7.85	7.71
160	6.20	6.25
140	5.02	4.99
120	3.93	3.92
100	3.04	2.99
80	2.22	2.20

We see from the example which we have just given, that it is possible by intermediate observations on cooling in air to estimate separately the loss of heat due to contact and to radiation, and that for this it is necessary to observe the cooling of the same body under two different conditions of surface. But the mode of calculation depends, on the one hand, on the supposition that the quantity of heat carried off by the air is independent of the nature of the surface of the body, and on the other, on this principle, that bodies of a different nature preserve at all temperatures the same ratio between their radiating power. These two proposit are rigorously true, but can only be proved by d experiments, such as those which we have stated ab and though Mr. Leslie has adopted them in the which he has made of the principle which we have explained, his results have not all the accuracy could be desired, because he has always calculate velocities of cooling according to the Newtonian l

The laws relative to each of these two effects, w concur to produce the cooling of a body plu into a fluid being separately established, it is m necessary to unite them in order to deduce the law of cooling. The velocity v of this cooling fo excess t of temperature will be then expressed b formula

$$m\,(a^t - 1) + n\,t^b.$$

The quantities a and b will be for all bodies an all fluids equal, the first to 0.0077, and the secon 1.233. The coefficient m will depend on the di sions and the nature of the surface, as well as the absolute nature of the surrounding body; the c cient n, independent of that absolute temperatu well as of the nature of the surface of the body, vary with the elasticity and with the nature of th in which the body is plunged, and these variation follow laws which we have already established.

This formula shows us in the first place, as we announced at the commencement of this memoir, the law of cooling in elastic fluids changes witl nature of the surface of the body. In fact, whe change takes place the quantities a, b, and n pre their values: but the coefficient m varies proportio to the radiating power of the surface. If we repr its new value by m', the velocity of cooling will be

$$m'\,(a^t - 1) + n\,t^b$$

a quantity which does not remain proportion $m\,(a^t - 1) + n\,t^b$ when t changes.

Let us now examine how the ratio of these velocities varies, and let us suppose, in order to fi ideas, that m is greater than m'; that is to say, t belongs to the body which radiates most. We m the first place satisfy ourselves by means of the of the differential calculus, that the fraction

$$\frac{m\,(a^t - 1) + n\,t^b}{m'\,(a^t + 1) + n\,t^b}$$

becomes equal to $\frac{m}{m'}$, whether we make $t = 0$, or t

If we suppose t very small, the quantity $a^t - 1$ duced to $\log a\; t$, and the preceding ratio bec dividing by $t \log a$

$$\frac{m + \frac{n}{\log a}.\, t^b - 1}{m' + \frac{n}{\log a} \cdot t^b - 1}$$

Under this form it is evident that the ratio diminish in proportion as t increases, b being gr than 1; but this ratio, after having diminished again increase, since it must resume at unity the which it has when $t = 0$. From this it is ea arrive at the truth of the principle which we have blished at the beginning of this memoir, and comes to this, that when we compare the laws of co in two bodies with different surfaces, the law is rapid at low temperatures for the body which ra the least, and less rapid on the contrary for the body at high temperatures. This may be easily ve in the following table, where we have inserted the velocities of cooling of the naked thermometer, and of the silvered thermometer, and the ratios between these velocities.

Excess of temperature of thermometers.	Velocities of cooling of the naked thermometer.	Velocities of cooling of the silvered thermometer.	Ratio of these velocities.
260°	24.42°	10.96°	2.23°
240	21.12	9.82	2.15
220	17.92	8.59	2.09
200	15.30	7.57	2.02
180	13.04	6.57	1.98
160	10.70	5.59	1.91
140	8.75	4.61	1.89
120	6.82	3.80	1.80
100	5.56	3.06	1.81
80	4.15	2.32	1.78
60	2.86	1.60	1.79
40	1.74	0.96	1.81
20	0.77	0.42	1.85
10	0.37	0.19	1.90

The mere inspection of the numbers inserted in the last column, fully confirms the fact announced above. We perceive likewise, the ratios of the velocities of the two thermometers remaining nearly the same for the excesses of temperature between 40° and 120°. This circumstance, resulting obviously from the ratios increasing after having diminished, has probably contributed to persuade Mr. Dalton that the law of cooling in air must be the same for all bodies. If the above series were carried farther, we should find that the ratio of the velocities of cooling, which is already equal to 2.23 for an excess of temperature of 260°, increases rapidly as that excess augments, and that it approaches more and more to the number 5.707, to which the fraction $\frac{m}{m'}$ is equal in the case of glass compared with silver.

We see from this to what a degree the consequence deduced by Mr. Leslie, from experiments made at low temperatures, are inaccurate. For having imagined, as we have said in the beginning of this memoir, that the ratio which we have determined above would continue always to diminish, he had supposed that it would terminate by becoming almost equal to unity, so that at high temperatures the total losses of heat would be almost independent of the state of the surfaces. The laws which this philosopher has proposed, refuted as they have been by Dalton, or even by the anterior researches of Martine, may be all overturned by a single argument; for all these laws make the velocity of cooling depend solely on the excess of temperature of the body above that of the surrounding medium, while experience proves that, other things being equal, this velocity changes, in a remarkable degree, with the temperature of the fluid which surrounds the body.

It is needless, therefore, to enter into any discussion on this subject; for admitting that the laws of which we have spoken, represent the results of experiment within the limits in which they have been determined, it is certain from all that precedes, that when we extend them beyond these limits we arrive at results very different from the truth. We may, by considerations analogous to those which we have used above, determine in what manner the law of total cooling changes for the same body with the nature and density of the gases.

The total velocity of cooling is expressed by

$$m\,(a^t - 1) + n\,t^b$$

If we consider another gas, or the same gas, at a different density, the velocity of cooling will be for the same body

$$m\,(a^t - 1) + n'\,t^b$$

for the coefficient n is the only part of the expression which changes in this case.

On comparing these two expressions, we find that their ratio becomes equal to unity, whether we make $t = 0$ or $t = x$. Hence the total velocities of cooling in different gases approach equality at very high temperatures, and very low, while in any intermediate part of the scale these velocities may be very different. This result is sufficient to show the inaccuracy of the processes which Mr. Dalton and Mr. Leslie employed, to compare the losses of heat due to different gases; for those processes are founded on the supposition, that the total velocities of cooling in the different gases preserve the same ratio at all temperatures. But from a very singular circumstance, upon which it is needless to insist, the particular temperature at which they operated renders the error very small, and they were far from ascribing it to their mode of calculation. Accordingly their determinations, as we have said before, are very near the truth, provided they be restricted to the circumstances under which they have been made.

The necessity of estimating separately the influence of each of the causes which modify the progress of the cooling of a body, not having allowed us to bring together the different laws at which we have arrived, we conceive that a summary recapitulation will be so much more useful, because we shall have it in our power to reestablish the natural order, which the description of experiments and the discussion of the results have often obliged us to interrupt.

Distinguishing, as we have done, the losses of heat due separately to the contact of fluids and to radiation, we soon perceive that each of these two effects is subject to particular laws. These laws ought to express the relations which exist between the temperature of the body and the velocity of its cooling for all possible circumstances. We must recollect, that by velocity of cooling we mean always the number of degrees which the temperature of the body would sink during an infinitely small and constant interval of time.

First Law.—If we could observe the cooling of a body placed in a vacuum surrounded by an enclosure totally destitute of heat, or deprived of the faculty of radiating, the velocities of cooling would decrease in a geometrical progression, while the temperatures diminished in an arithmetical progression.

Second Law.—The temperature of the vacuum in which the body is placed remaining constant, the velocities of cooling for excesses of temperature in arithmetical progression decrease as the terms of a geometrical progression diminished by a constant number. The ratio of this geometrical progression is the same for all bodies, and is equal to 1.0077.

Third Law.—The velocity of cooling in vacuo for the same excess of temperature increases in a geometrical progression, while the temperature of the vacuum increases in an arithmetical progression. The ratio of this progression is likewise 1.0077 for all bodies.

Fourth Law.—The velocity of cooling due to the sole contact of a gas, is entirely independent of the nature of the surface of the body.

Fifth Law.—The velocity of cooling due solely to the contact of a fluid, varies in a geometrical progression, while the excess of temperature itself varies in a geometrical progression. If the ratio of this second progression be 2, that of the first is 2.35, whatever be the nature of the gas and its elastic force. This law may be likewise enunciated by saying, that the quantity of heat carried off by a gas is in all cases proportional to the excess of the temperature of the body raised to the power 1.233.

Sixth Law.—The cooling power of a fluid diminishes in a geometrical progression when its tension itself diminishes in a geometrical progression. If the ratio of this second progression is 2, the ratio of the first is 1.366 for air; 1.301 for hydrogen; 1.431 for carbonic acid; and 1.415 for olefiant gas.

This law may likewise be presented in the following manner:—The cooling power of a gas is, all other things being equal, proportional to some certain power of the pressure. The exponent of this power, which depends on the nature of the gas, is 0.45 for air; 0.315 for hydrogen; 0.517 for carbonic acid; and 0.501 for olefiant gas.

Seventh Law.—The cooling power of a gas varies with its temperature in such a manner, that if the gas can dilate, and if it preserves always the same elastic force, the cooling power will be as much diminished by the rarefaction of the gas, as it is increased by its augmentation of temperature, so that, ultimately, it depends only on its tension.

We see from these propositions that the total law of cooling, which would be compounded of all the preceding laws, must be very complicated; we shall not, therefore, attempt to translate it into ordinary language. We have given it in the course of the memoir under a mathematical form, which permits us to examine all its consequences. We shall satisfy ourselves with remarking, that it is doubtless to the very complicated nature of this law that we must ascribe the little success of the attempts hitherto made to discover it. It is obvious that we can only arrive at it by studying apart each of the causes which contributes to the total effect.

References in (172):

(*a*) Newtoni *Opusc.* ii. 423. (*b*) *Nov. Com. Ac. Petrop.* i. 195. (*c*) *Essays on Heat*, p. 72. (*d*) *Nov. Com. Soc. Gott.* viii. 74. (*e*) Leslie, *on Heat.* (*f*) *Annales de Ch. et de Ph.* vii. 225, &c.; or Thomson's *Annals*, xiii. p. 113.

Radiation.

(173.) Hitherto we have considered the property well known and generally understood by the term of Radiation in the light of a gradual loss sustained by the heated substance, analogous to the slow dissipation of electricity from an excited body. We now proceed a step further in the inquiry, and attempt to give a summary of the researches of those who have traced the progress of these rays, be they real, or be they only imaginary, and adopted as a mode of speaking for the purpose of convenient illustration.

Mariotte.

The earliest experiments usually cited upon this subject are those of Mariotte. (*b.*) He states that "the heat of a fire reflected by a burning mirror is sensible in its focus; but if a glass screen is interposed between the mirror and the focus, the heat is no longer sensible."

In pursuing this question Lambert (*c*) mo
cularly attempted to separate the effect of t
from that of the heat; with this view he int
the light of a clear fire with a large lens, a
that it produced scarcely any appreciable hea
hand placed in the focus; but by two concave
he reflected the heat of burning charcoal, so as t
to combustible bodies at a distance of more than

Scheele also directed his inquiries to this poi
first made use of the term Radiant heat, and
that it did not communicate warmth to the air
which it was made to pass. He proved also
passage through a space filled with air
changed in direction by a current in that air,
its intensity was not diminished by violent a
taking place in the air. By the interposition o
of glass between the fire and his hand, the h
intercepted, though the light was transmitted an
afterwards be concentrated to a focus by a le
states that a glass mirror reflects the light of a
not the heat, but that a polished metallic su
flects both the light and the heat. The
reflector therefore may be exposed to the fire, a
in the hand with safety; but by blackening its
the reflecting power was destroyed, and in four
it became too hot to hold. (*d.*)

MM. Saussure and Pictet repeated the prece
periments with a very convenient apparatus rep
in fig. 23. Two concave mirrors of polished t
a foot in diameter, were placed at a distanc
feet apart; the focal length of the mirrors
inches each. In the focus of one was the bu
thermometer, and in the focus of the other they
a ball of iron 2 inches in diameter, which w
heated red, and then suffered to cool until it c
be visible in the dark. Another thermome
placed at the same distance from the heated
the former one, but without the focus of the re
mirror. Upon the introduction of the heated
its place the thermometer instantly rose, and
minutes indicated an increase of temperature
Reaumur, while that not in the focus advanc
2°.5, setting out from the same point. Here
thermometers, being at equal distances, may
posed to have been equally affected by the dir
from the hot ball; the one without the focus
no other heat, but the focal thermometer recei
direct rays, and also was on the spot for the re
of other calorific rays, had such been reflected
mirror on the same principle as those of light;
so marked an effect was produced upon this
meter, it is fair to ascribe the difference to the r
power of the mirror, and to infer that the m
radiant heat is analogous to that of light, proce
right lines, and following the same law in its re

In a repetition of this experiment by M. Pict
a lighted candle in place of the heated ball, t
thermometer rose from 4°.6 to 14° Reaumur.

M. Pictet particularly endeavoured to pro
these effects were not due to the action of light
might possibly be supposed to exist, though in
too feeble to excite the ordinary sensation of
He therefore interposed a plate of glass betw
radiant body and the thermometer. In this ca
of light would be supposed to have a free p
and if (as it proved) the calorific rays were int
by the glass screen, their separate existence and

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nature must be admitted. The candle was placed in one focus; and when it had raised the thermometer in the opposite focus from 2° to 12°, the glass screen was interposed, and in nine minutes the thermometer fell to 5°.7, and again rose on the removal of the glass. He was disposed to attribute the degree of heating effect which still remained, after the interposition of the screen, partly to its not in reality intercepting all the calorific rays, and partly to its own acquired increase of temperature, by which it in turn became a source of radiant heat to the second mirror.

(174.) Again, a small glass flask, containing more than two ounces, was filled with boiling water, and placed in one focus; the mirrors being 10½ feet from each other; while a small Fahrenheit's thermometer occupied the other focus. In two minutes the rise was from 47° to 50⅛°, and upon the removal of the matrass the mercury again fell. It seems clear from these experiments, that calorific rays exist independently of luminous rays; that they proceed in right lines from heated bodies; and that they are capable of reflection from polished metallic surfaces.

It was long known that blackened substances received or absorbed more heat when exposed to the rays of the sun, than others did which had not been so prepared; and Scheele's experiment, with the blackened reflector, had proved that in this respect the calorific rays from a common fire followed the same law with those proceeding from the sun. This also Pictet proved by a slight variation upon the last experiment. The bulb of the thermometer which when clean rose from 47° to 50⅛° was blackened, and then in the same time it rose from 51¼° to 55¼°.

(175.) A concave mirror of glass was substituted in place of the metallic reflector, but by this scarcely any effect could be produced upon the thermometer in one focus, with the heated iron ball in the other. This also proved the inferiority of glass as a reflector of heat. M. Pictet could not ascertain satisfactorily whether the calorific rays were capable of refraction or not. He also attempted to measure the velocity with which they moved; for this purpose he placed the reflectors at a distance of 69 feet from each other, having in the one focus a heated ball, and in the other a delicate air thermometer. A cloth screen was interposed between the reflectors. Upon the removal of this screen the rise of the thermometer was instantaneous. Within this distance then it seemed, that no perceptible interval elapsed between the passage of the calorific rays from one part of the apparatus to the other.

rchell.

(176.) In the chronological order of research we now arrive at a name with the rare distinction of standing successively for two generations preeminent in the annals of science. In the year 1800, Dr. Herschell published a much more minute dissection of the solar beam than had before been attempted. In his astronomical observations he had been struck by the different sensations of heat experienced in the use of screens of coloured glass. Rochon had found that an air thermometer exposed to the action of the coloured rays of the prismatic spectrum, rose from the violet to the red extremity; and he considered the ratio of heating power between the clear red and deepest violet to be about that of 8 to 1; and that in the intermediate stages the decrease of heat was rapid in proceeding towards the violet extremity. (*f*.)

Dr. Herschell mounted a piece of pasteboard upon a movable frame, so that one or more of the coloured pencils in the prismatic spectrum could be brought upon the bulb of a mercurial thermometer, and thus the relative heating powers might be compared. The progressive increase of effect in moving from the violet to the red extremity seemed to follow these proportions. In ten minutes the thermometer rose in the red ray 7° Fahrenheit; in the green 3°.5; and in the violet ray 2°.

But in the prosecution of these experiments Dr. Herschell found the heating power extended beyond the extreme limit of the visible red rays, and that it was even quite without the visible spectrum that the maximum heating position existed. From this result it seemed to follow, that the refrangibility of the calorific rays was greater than that of the luminous solar rays; and that, therefore, when the sunbeam was concentrated by a convex lens the most perfect focus of light would not strictly coincide with that of heat. This was submitted to an experiment which seemed to prove, that the distance of the focus of heat from the lens exceeded that of the light by not less than one quarter of an inch. (*g*.)

(177.) These experiments were repeated by Sir Henry Englefield, who obtained similar results, which are shown in the following table:

				Fahrenheit.		
In the blue.	in	3′	from	55°	to	56°
In the green		3	....	54	..	58
In the yellow		3	....	56	..	62
In the full red.		2½	....	56	..	72
In the confines of red		2½	....	58	..	73½
Quite out of the visible light. .		2½	....	61	..	79

Here it appeared, that beyond the full red light, and where only a faint blush of red was perceptible, the greatest heat existed; and that even half an inch beyond the edge of the red ray, where there was no illuminating power, the heat was still greater than in the red ray. (*h*.) Mr. Leslie's experiments on this point indicated the same, or even a greater, increase of calorific effect, in traversing the spectrum from the blue to the red extremity; but he did not find an excess of heating power beyond the red rays.

This subject we shall have to resume hereafter; but to return to our point. It appears clear, that as the calorific rays are separated from the calorific or visible rays by transmission through a prism, both the former and the latter are bent from their course, or suffer refraction. And as the calorific rays are dispersed over a space greater than that of the area of the prism, and greater even than that occasioned by the visible rays of light, it follows that a beam of radiant caloric must consist of rays differing in refrangibility, and also that the range of its refrangibility is even more extensive than that of the coloured rays.

Dr. Herschell further endeavoured to ascertain whether the radiant calorific issuing from a heated body were also refrangible. A lens was placed at a small distance from a burning candle; a pasteboard screen being interposed with a hole in it, so that only a pencil of direct rays proceeded from the candle to the lens, and being there refracted upon the bulb of a thermometer, a rise of 2½° was obtained in the course of three minutes. Similar experiments upon the rays from a common fire, from a mass of red hot iron, and from a mass of iron not heated to redness, and also having presented the canister's blackened side, refill it with boiling water. The coloured liquor will rise through a small but visible space. Rub off the silvering from the back of the mirror, and the effect will remain unaltered. Roughen the surface of the back by grinding it with sand or emery, the same effect will still be perceived; a decisive proof, that the reflection of heat is produced entirely at the anterior surface of the mirror. Over that surface spread a body of China ink, which will form an even and glossy coat; replace the mirror, and the effect now becomes altogether insensible. Cover the face of the mirror with a sheet of tin-foil, by pasting and carefully adapting it to the curvature, and smooth away as much as possible all wrinkles, a very great change will instantly be perceived in the degree of the performance. The effect of this reflector will ten times exceed that produced by the naked mirror.

"Hence it appears, that independent of the polish and figure, the nature itself of the substance of which a surface consists, has a most predominant influence in determining the measure of the reflection of heat; indeed the former requisites are comparatively of much inferior consequence. The very different effects of metallic and vitreous surfaces, in the reflection of heat, cannot fail to strike the most indolent observer.

"It may be desirable to exhibit the several results of the foregoing experiments in a collective view. Suppose that the bright side of the canister fronts a concave mirror, and that the focal ball properly placed is coated with tin-foil; an effect very minute indeed, but under favourable circumstances still perceptible, will be produced. Call this 1. Cover the face of the mirror with tin-foil, and the liquor of the differential thermometer will mount to 10. Remove the cap from the focal ball, and the action will be increased to 50. Now present the blackened side of the canister, and the extreme effect will be produced equal to 400. All these experiments succeed equally with cold, which exhibits the same diversified effects, and after the same proportions, though necessarily more limited." p. 23.

(182.) It appeared also, that a considerable degree of aberration takes place in the reflection of heat; for the calorific body might be moved out of the axis of the reflector at right angles to that line, without immediately destroying the heating effect upon the focal thermometer. At the distance of one inch the effect did not appear to be diminished, and it might be withdrawn 7 or 8 inches before the calorific effects were entirely lost. From this it follows, that the maximum calorific effect, with the heating body in the axis, will not be found in the true optical focus of the reflector, but rather nearer to the mirror. Accordingly by advancing the thermometer half an inch towards the reflector, the heating effect was augmented more than one-third; and even at one inch it was greater by one-fourth; but by a motion in the contrary direction the effects decreased as rapidly. p. 64.

(183.) Professor Leslie's experiments with interposed screens, though exceedingly instructive, have been subsequently so much improved upon by others, that we shall not here pursue them in detail: one, however, we may select of great general interest: "Cause two sheets of tin, about ten inches square, to be hammered quite flat and smooth, and paint one side of each with a thin coat of lamp-black. Arrange the apparatus as usual, and having joined together the tin plates with their clear surfaces touching, fix them to a vertical frame, placed between the reflector and the heated body: the differential thermometer will rise 23 degrees. Invert the position of the plates, so that the black sides come in contact, and the thermometer will sink down to zero; but if either plate be removed, the liquor will rise 4 degrees." The interposed mass of matter is the same in both the two first cases; but in the former, the two exterior surfaces are proper for the transmission of calorific effect, the side next to the heated body being a good absorber of heat, the metal between a good conductor, and the next black surface a good radiator. Again, in the latter case, the first surface is a bad absorber, and the second surface is a bad radiator. Mr. Leslie had before shown that metallic plates, even as thin as gold-leaf, intercepted the direct passage of the calorific rays. But that transparent bodies, such as glass, did not entirely so. These subjects, however, have been ably examined by Laroche and other subsequent experimentalists.

(184.) We have one slight subject of complaint against Mr. Leslie's work; that it has neither index nor table of contents; hence it is sometimes difficult to refer to experiments which it would be convenient to examine in connection with each other. The table of comparative radiating powers, as given in his experiments, will be found in the Appendix, No. XIII. Also a table of the comparative powers of substances made use of as reflectors, No. XIV. By applying coats of certain substances to one surface of the tin cube, it appeared that where these could be extremely thin, there was a marked difference in the effects produced; such was the case with some varnishes. Thus, where the effect of one coat of jelly applied to one surface of the tin was 38°, the effect of four such layers applied to another surface, was augmented to 54°. This increase continued till the thickness of the jelly was $\frac{1}{1000}$ of an inch, and then remained unchanged by further additions. With regard to metals, it seemed that a plate of the finest leaf that could be applied, rendered the radiating power as great as a thicker plate of the same metal; but it was supposed that differences might have been found within certain limits, as in the jelly, had it been possible to increase the tenuity of the metals sufficiently. (*i.*)

(185.) Count Rumford's memoir affords a striking instance of a circumstance by no means uncommon in the annals of science; that there is a certain point at which the generally diffused knowledge relating to any subject arrives; and that then, as there may remain but a few slight steps to reach some important developement, these steps are readily passed over by more than one individual at the same instant. Such was the case here, the Treatise of Professor Leslie, and the Memoir of Count Rumford, both appeared in the same year; and as they present two series of independent but highly accordant results, they may fairly be considered as strongly corroborative of each other. (*k.*)

M. Delaroche.

(186.) The original Memoir of M. Delaroche, we regret to state we have not been able to examine, and therefore can only offer the following condensed outline of its contents, extracted from Thomson's *Annals.* (*p.*)

"I propose in this memoir to state several propositions which appear to me capable of throwing some light on the theory of radiant heat; and which I think I have established by decisive experiments. These experiments, indeed, were made with sufficient care to only $\frac{1}{5}$ of what it had been within the red ray itself." Do these differences (say the reporters,) depend upon the matter of the prisms and the difference of the apparatus, or on some circumstances depending upon the phenomenon itself?

M. Berard wished to know 'f these properties would exist in each of the pencils, into which the ray divides itself in passing through a rhomboid of Iceland spar. He made a ray of solar light pass through a prism of this substance. Each of the two spectra exhibited the same properties. In both the calorific power diminished from the violet to the red end, and it existed beyond the last visible red rays. Thus, whether this faculty be inherent in the solar rays or not, when these rays are divided by a crystal it goes along with each.

But in this operation, the luminous molecules are *polarized* by the crystal. Do the invisible rays of heat experience the same effect? To determine this point, M. Berard received the solar ray upon a polished and transparent glass, which polarized a portion of it by reflection. This reflected ray was then received upon a second glass, fixed in an apparatus, which permitted it to be turned round the ray under a constant incidence, and this incidence itself was determined in such a manner, that in a certain position of the glass, the reflection ceased to take place. We know, from the experiments of Malus, that a glass may be always disposed in such a manner that this condition is fulfilled. By collecting with a mirror the calorific and luminous rays reflected from the second glass, and directing them upon a thermometer, M. Berard found that as long as light was reflected the thermometer was elevated, and of course the heat was reflected likewise; but when, from the position of the second glass, the light was totally transmitted, the heat was transmitted at the same time, and the thermometer was not elevated. In this experiment, then, as well as the preceding, the calorific principle, whatever it may be, never separates from the luminous molecules.

To the ray of solar light employed in this experiment, M. Berard substituted a pencil of radiant heat proceeding from a body hot, but not red, and even not luminous. The effect was the same as before. The thermometer rose when the second glass was so situated as to reflect light, and it did not rise when the second could not reflect light. Therefore the particles of invisible radiant heat are modified by reflection precisely like light.

(188.) The following observations by M. Berthollet turn so much upon the general features of this question, that we cannot forbear from quoting them, although we are most scrupulously anxious not to intrude upon the province of *physical optics*; a subject at present under preparation for this work, in hands better qualified for the task than any others which this country could produce.

The report goes on to state, " without attempting to decide between two opinions, which both go beyond the facts observed, we may at least weigh their relative probabilities, and compare the number of hypotheses necessary in each, to represent the same number of facts. If we wish to consider solar light as composed of three distinct substances, one of which causes light, another heat, and the third chemical combinations, it will follow that each of these substances, is separable by the prism into an infinity of different modifications, like light itself; since we find by experiment that each of the three properties, chemical, colorific, and calorific, is spread, though unequally, over a certain extent of the spectrum. Hence we must suppose, on that hypothesis, that there exist three spectra, one above another, viz. a calorific, a colorific, and a chemical one. We must likewise admit that each of the substances which compose the three spectra, and even each molecule of unequal refrangibility which constitutes these substances, is endowed, like the molecules of visible light, with the property of being polarized by reflection, and of escaping from reflection in the same positions as the luminous molecules.

"Instead of this complication of ideas let us conceive simply, according to the phenomena, that light is composed of a collection of rays unequally refrangible, and of course unequally attracted by bodies. This supposes original differences in their size and velocity, or in their affinities. Why should those rays which differ already in so many things, produce upon thermometers, or upon our organs, the same sensations of heat or light? Why should they have the same energy to form or separate combinations? Would it not be quite natural that vision should not operate on our eyes, except within certain limits of refrangibility; and that too little or too much refrangibility, should render it equally incapable of producing that effect? Perhaps these rays may be visible to other eyes than ours; perhaps they are so to certain animals; which would account for certain actions that appear to us marvellous. In a word, we may conceive the calorific and chemical faculty to vary through the whole length of the spectrum, at the same time with the refrangibility, but according to different functions; so that the calorific faculty is at its minimum at the violet end of the spectrum, and its maximum at the red end; while, on the other hand, the chemical faculty expressed by another function, is at its minimum at the red end, and at its maximum at the violet end, or a little beyond it. This simple supposition, which is only the simple statement of the phenomena, equally agrees with all the facts hitherto observed, and accounts for those established by M. Berard, and even enables us to predict them. In fact, if all the rays which produce these three orders of phenomena are rays of light, they must of course be polarized in passing through Iceland crystal, or in being reflected from a polished glass with a determinate incidence: and when they have received these modifications, they must be reflected by another glass, if it is properly placed, to exert its reflecting energy on the luminous molecules. On the other hand, if that force is null on the visible molecules, the invisible light will not be any longer reflected: for the cause which occasions or prevents reflection, appears to act equally upon all the molecules, whatever their refrangibility may be. It ought, therefore, to act upon the molecules of invisible light, the condition of visibility or invisibility relating merely to our eyes, and not to the nature of the molecules which produce these sensations in us."

On this subject, we have but to mention several papers by Mr. Powell, and, as the shortest possible abstract of his views, we present the following from his own paper in the *Philosophical Transactions*.

1. " That part of the heating effect of a luminous hot body which is capable of being transmitted in the way of direct radiation through glass, affects bodies in proportion to their *darkness of colour*, without reference to the texture of their surfaces.

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l'Acad. 1682. (*c*) Lambert, *Pyrometrie*; or Saussure, *Voyage, &c.* iv. p. 119. (*d*) Scheele, *Exp. on Air and Fire*, p. 67—71. (*e*) Pictet, *Essais de Physique*, vol. i. p. 63. (*f*) Rochon, *Phil. Mag.*, xlv. p. 408. (*g*) Herschell, *Phil. Trans.*, 1800, p. 272, 309, and 446; also 1803, p. 464. (*h*) Englefield, Brande's *Jour.*, i. 203. (*i*) Leslie, *Inquiry into the Nature of Heat*, 1804. (*k*) Rumford, *Phil. Trans.*, 1804, p. 90. (*l*) Maycock, Nicholson's *Journal*, xxvi. p. 75. (*m*) Dalton, *New Syst. Ch. Phil.*, 1807, p. 118, &c. (*n*) Hutton, *on Light and Heat, &c.* 1794. (*o*) Prevost, *Essai sur la Calorique rayonnante*, Geneva, 1809. (*p*) Delaroche, *Jour. de Phys.*, lxxv. p. 201, or *An. Phil.*, ii. p. 100, 1813. (*q*) Berard, *An. de Ch.*, lxxxv. 309, or Thomson's *Annals*, ii. 161. (*r*) Leslie, *on the Relations of Atmospheric Air to Heat and Moisture*, 1814. (*s*) Fourier, *An. de Ch. et de Phys.*, iv. 128. (*t*) Ritchie, Brewster, *Jour.*, 1824, xi. 281, and xii. p. 15. (*u*) Powell. *An. Phil.*, xxiii. p. 321 and 401; xxiv. p. 81 and 287; xxv. p. 201, 359, 401; and *Phil. Trans.*, 1825, part i. Fischer, *Geschichte der Physik, art. Warme.* (*w*) Biot, *Phys.*, ch. ii. and iii. vol. iv. Caloric. (*x*) Murray, *Chemistry*, i. p. 327—371. (*y*) Thomson, *Chemistry*, i. 75—87. (*z*) Thenard, *Systême de Ch.*, i. sec. 36, &c. See also Arago, on Daniell's results from atmospheric radiation, *An. de Ch. et de Phys.*, xxvi. p. 375, and answer to these *An. Phil.*, Oct. 1824, p. 257. Prevost, *Mém. de la Soc. Phys. &c. de Geneve*, 1824, tom. ii. part ii. p. 161. Meikle, *Phil. Mag.* January, 1825, p. 10. Fourier, *Mém. de l'Acad. Par.* tom. v.; also *An. de Ch. et de Ph.*, iii. (1816;) also iv. (1817,) p. 128; also vi. (1817,) p. 259. Poisson, *Ibid.*, xxvi. p. 225 and 442. Fourier, *Ibid.*, xxvii. p. 236 and 260. Poisson, *Ibid.*, xxviii. p. 37. Fourier, *Ibid.*, xxviii. p. 337. (*aa*) Brewster, *Phil. Trans.*, 1816, p. 106.

CHAPTER IV.

ON THE CONDUCTING POWERS OF BODIES.

Heat. (198.) The phrase, Conducting power, though now so familiar as to be readily understood by every one, and therefore as we hope secure from inducing any false notion of the operation of caloric, must nevertheless be admitted to be logically objectionable. In strict language it seems to imply some active property in the particles of matter, by which the effect or substance of caloric (be it which it may) is passed on from each molecule in succession to the one next adjoining to it: while in fact it is possible that the true case may be one of resistance, that the particles of matter oppose the free motion of heat which otherwise would take place, and compel it to undertake the more tedious process of inducing a certain effect upon the first particle acted upon, which is in turn to act upon the next adjoining one, and so on.

Whether the molecules of matter be or be not in contact, and consequently whether all the effects even in solids are necessarily those of radiation at small distances from one particle to another, as from so many screens placed consecutively, is a point quite beyond our present knowledge, but is also, happily, immaterial to our purpose.

It seems to be the general tendency of caloric to become so diffused among matter of every kind as to produce uniformity of temperature. In the preceding chapter we have treated of the motions of caloric in free space and in aeriform fluids, where it moves by radiation. We here therefore consider its motion in homogeneous bodies, which, as we have seen, is estimated by their *conducting power*, or to use a better word, proposed by M. Fourier, their *specific permeability*: a property peculiar in degree for each substance, and independent of the state of its surface.

Corresponding to the three physical states of ponderable matter, we shall now consider the specific permeability or conducting power of heat, in solids, liquids, and gases.

§ 1. *Conducting Power of Solids.*

Solids. (199.) If heat or cold be applied to the surface of any body, that is to say, if caloric be added to or abstracted from the exterior molecule of any mass of matter, this effect will be continued to the molecule next adjoining, and so on. Thus the change of temperature is transmitted through the mass of matter. In this illustration we do not consider whether the first molecule exerts any influence upon the third, other than through the medium of the second, or not; neither is this a question which we are able to resolve; for if we were, the doubts which have been expressed at the beginning of this chapter, respecting the mode of the transmission of heat, would be at an end.

That bodies differ greatly in the facility with which they permit the motion of caloric or transmit its effects, is a matter of daily observation. If two rods, the one of metal and the other of earthenware, have each an end placed in the fire, the metal rod will become heated much sooner, and the calorific effect will be transmitted along it much further than in the earthenware one. If the rods be of considerable length, there will be found a point in each, (the focus of heat remaining constant) at which the increment of temperature received from the next preceding heated molecule being exactly equal to the decrement produced by the effect of radiation, and the contact of the air; no further elevation of temperature will beyond that point be produced.

Although it is not, as we shall shortly show, a law of rigid accuracy, yet it may be roughly stated, that those substances which possess the greatest density have also the greatest conducting power. Thus the metals are the best conductors, then the hard woods, and so on.

(200.) The relative conducting power has been the subject of many experiments, with a view to ascertain whether any connection could be traced between that and their other physical or chemical properties. The metals seem to offer the most promising subject for such researches, in consequence of their uniform nature and continuity. How near their solidity approaches to perfection we are however ignorant; and in the case of woods and other porous bodies, the presence of air, a notoriously bad conductor, must materially interfere with the process.

On this principle alone, if not from any other, we may account for the very different conducting power of the same substance in different states of aggregation. Thus a mass of iron filings conducts heat much more slowly than an integral mass of iron; and saw-dust much worse than the wood from which it has been formed.

(201.) Amongst the earliest comparative experiments those of M. Richman have been thus briefly described. "He enclosed the bulb of a thermometer in similar hollow balls of the metals, which were plunged into boiling water until the thermometer in each rose to the same point. They were then removed and exposed to the atmosphere, and the time which elapsed, while the enclosed thermometer cooled a certain number of degrees, was marked: the relative conducting power was supposed to be as the times of cooling." His results need not be stated, as they are rendered quite nugatory by considering that in fact the cooling would greatly depend upon the radiation of the surfaces of these metallic shells. (*a.*)

(202.) Franklin's method as employed by Ingenhousz in 1780 is more direct and simple. Equal wires of the several ductile metals were passed through a flat horizontal disc of wood, and all left standing at a considerable but equal height above its surface. This results are just subjects of comparison, and may guide us to many useful explanations and applications.

Applications.

Thus we are taught the reason why wool and down, feathers and furs, are such warm articles of clothing; because in the ordinary state in which we employ them, the effect of their own bad conducting property, and that of the air retained in their interstices, prevents the abstraction of caloric from our bodies. From its porous nature, snow is a very bad conductor; and thus a mantle producing uniformity of temperature is provided for the protection of vegetables from the more intense colds of winter.

(206.) Heat and cold when referred to our sensations are but comparative terms, and depend upon the temperature of our bodies at the time of experiment. This admits of a very familiar illustration. Let a hand be dipped into a basin of water at about 90° Fahrenheit, and it will feel warm; then let the hand be plunged into another basin at about 70°, this will produce the sensation of cold. But if the same basin of water at 70° be made use of after a bath of spring water, it will produce the sensation of warmth. Thus the same water is warm or cold to our sensations, according to the state of bodily temperature at which we make the experiment.

But by the conducting powers of bodies we readily explain another branch of our sensations. In a room of uniform temperature all substances in it would produce equal indications upon the scale of the thermometer. But if we touch these different substances in succession, very different sensations will be produced; a piece of metal will feel much colder in the ordinary state of the atmosphere than any marble or stone or glass, and these colder than a table of wood or a mass of paper. The contrary will take place if all these bodies be heated in the sun to a temperature beyond that of our animal heat. The reason is apparent, each of these substances has a different conducting power, and that which is the best conductor will carry off heat from our bodies with the greatest rapidity, and therefore will produce in us the greatest sensation of cold.

Again, it is in consequence of bad conducting power that glass and earthenware vessels are so easily broken by the sudden application of heat. The exterior portion which is first affected undergoes expansion, but as this effect has not been carried on by the progress of heat towards the interior of the substance, the equilibrium of cohesion between the particles is destroyed, and the vessel is broken.

(207.) These principles also are of frequent application in the arts and in domestic economy. If we wish to keep any body hot or cold, speaking comparatively with reference to the mean temperature of the air, or in other words to cut off the radiation and conducted transmission of heat, which tends to produce equilibrium of temperature in all bodies, we must employ clothings or screens of the worst conductors we can find. To keep the substance warm we wrap it in flannel, to keep a piece of ice from melting we do the same. Air is, as we shall see, a very bad conductor; therefore, in building an ice-house, in which the object is to prevent the access of caloric, a double wall having a hollow space within is found to be very effectual. Furnaces also are coated with a paste of clay and sand, to prevent the dissipation of heat. Wine coolers have recently been constructed for the purpose of confining the cooling effects of ice, or an artificial refrigerant mixture,—allowing as little loss as possible from the heating influence of the external air. To effect this, the outer tin case is made double, so as to leave a space of half an inch between the two plates of which it is formed. This space is either filled with powdered charcoal, or left vacant; and in either case, a vessel is produced of which the temperature within will remain many hours below that of the external air.

(208.) M. Pictet's experiment made with a view to ascertain whether heat were conducted more readily in one direction than in another, by the same substance, is worthy of observation. He contrived to enclose a metallic bar vertically in a vacuum, and then heated it exactly in the centre. Thermometers having been placed at the upper and lower extremities, it was found that the upper one manifested an increase of temperature more speedily than the lower one. (*g*.)

(209.) The problem of the communication of heat in solid bodies, has, like every other branch of the subject, been submitted to rigorous analysis by Laplace, Biot, Fourier, and Poisson. Of these, M. Biot is the only one who, as far as we know, has compared actual experiment with numerical calculation, and this only in the case of a metal bar heated at one extremity. For the details we must refer to his work. The formula investigated is

$$\log y = \log \mathrm{Y} - \frac{x}{\mathrm{M}} \sqrt{\frac{b}{a}}$$

where y represents the temperature of the air surrounding the bar in degrees of the thermometer. The temperature of the focus of heat being $\mathrm{Y} + y$. The distance of the point examined from the focus of hea is x, and a, b, are two coefficients constant for th whole length of any one bar only, and determinable b experiment; a is dependent on the specific permeability of the bar; and b represents the velocity o cooling for each point in the surface of the bar considered alone. (*h*.)

(210.) In speaking of the effects of caloric communicated to the surface of a body, and thence passi along through its substance, no limit has been assigne to the mode in which it may be imparted. Neither any such of consequence, for the effect is the same far as is known, whatsoever be the source from whi the caloric emanates. Such at least is the ca wherever heat is communicated from the exterior o substance, but of course the heat developed by percussion, or by Voltaic action, is differently excited a propagated.

The differences existing between the transmission heat by the contact of two substances possessing equal temperatures, seems simply to resolve itself i the case of those bodies before mentioned, (200.) wh differ in the state of their aggregation: the filings a the saw-dust. In such cases the rapidity with wh the one abstracts, and the other parts with its exc of caloric, follows, probably, a law arising out the conducting power and capacity of each bod respectively.

References from (198) to (210) inclusive:

(*a*) Richmann, *Com. Petrop.*, iv. p. 241. (*b*) Ingenhousz, *Jour. de Phys.*, xxxiv. p. 68; or *Nouvelle Expériences*, p. 380. (*c*) Meyer, *An. de Chim.*, xxx. p. 32. (*d*) Morveau, *An. de Chim.*, xxvi. p. 225. (*e*) Rumford, *Phil. Trans.*, 1782, or *Essays*, vol. ii. (*f*) Humboldt, *Jour. de Phys.*, xliii. p. 306. (*g*) Pictet,

applied to its surface, we may conclude with certainty, that the caloric has been conveyed by the conducting power of the fluid. In a hollow cylinder of ice, a thermometer was placed horizontally at the depth of one inch, its bulb being in the axis of the cylinder, and the part of the stem to which the scale was attached entirely without. As water could not be employed at the temperature at which it is requisite to make the experiment, on account of the property it possesses of becoming more dense in the rise of its temperature from 32° to 40°, oil was used. A quantity of almond oil at 32° was poured into the ice cylinder, so as to cover the bulb of the thermometer ½ of an inch. A flat-bottomed iron cup was suspended, so as to touch the surface of the oil, and two ounces of boiling water were poured into it. In a minute and a half the thermometer had risen from 32° to 32°.75; in three minutes to 34°.5; in five minutes to 36°.25; in seven minutes to 37°.5, when it became stationary, and soon began to fall. When more oil was interposed between the bottom of the cup and the bulb of the thermometer, the rise was less; but even when its depth was three quarters of an inch the rise amounted to 1°.5. With mercury the same results were obtained, the thermometer rising only with much more rapidity, from the mercury being a better conductor than the oil." (*f.*)

(214.) Few experiments have been made upon the relative conducting powers of fluids, and little is at present known on the subject, in consequence of the difficulty already adverted to, of separating the transportation by motion from the true conducting property. Obviously those substances which undergo the greatest expansion from heat will possess the most rapid carrying power, (fluidity being equal,) because in them currents will be formed with the greatest ease. Now since alcohol suffers a greater expansion from a given increment of temperature than mercury does; the circulation of its carrying currents must be more rapid than those in the metallic fluid; but yet as mercury adopts the temperature of a medium in which it is placed with greater rapidity than alcohol does, it must in reality be the better conductor.

(215.) Count Rumford found that when a thermometer was surrounded with a body of quicksilver, it required to be immersed in boiling water 36⅝ seconds to produce a rise of a certain number of degrees; but that to produce the same rise when surrounded in the same manner with water, 117 seconds were necessary. In this, which is obviously only a particular case of the general question, the conducting power of water is to that of mercury as $\frac{1}{117}$ to $\frac{1}{36\frac{5}{8}}$, or as 313 to 1000.

Dr. Traill. (216.) Dr. Traill endeavoured to ascertain the conducting power of different liquids, by finding the times requisite to produce an increment of 3° of temperature in a mercurial thermometer placed in the liquid submitted to trial. The caloric was transmitted downwards, from the extremity of a cylinder of iron, one inch in diameter, heated to 212°, and suspended in the liquid, so as to be half an inch distant from the bulb of the thermometer. The following are the results in minutes and seconds: (*g.*)

Mercury	0′	15″	
Saturated solution of sulphate of soda	6	30	
Water	7	5	
Proof spirit	8	0	nearly
Solution of sulphate of iron (1 salt 5 water)	8	0	
Liquor potassæ	8′	15″	
Cow's milk	8	25	
Solution of sulphate of alumina (saturated)	9	40	
Transparent olive oil	9	50	
Alcohol (*London Pharmacopœia*)	10	45	

Dr. Th son. (217.) Dr. Thomson states, that according to his experiments the conducting powers of mercury, water, and linseed oil, are in the following ratio: (*h.*)

Water	1	equal volumes.
Mercury	2	
Linseed oil	1.111	
Water	1	equal weights.
Mercury	4.8	
Linseed oil	1.085	

Dr. Br ster. (218.) The conducting property of liquids has also been proved on optical principles by Dr. Brewster, whose very curious experiments we most reluctantly commit to our readers through a reference only. (*i.*)

References from (211) to (218) inclusive:

(*a*) Rumford, *Essays*, vol. ii., or Thomson's *Chemistry*, i. p. 91. (*b*) Dr. Hope, *Edin. Trans.*, v. p. 394. (*c*) Thomson, Nich. *Jour.*, v. p. 529. (*d*) Nicholson, *Jour.*, 4to, vol. v. p. 197. (*e*) Dalton, *Manchester Mem.*, v. p. 473. (*f*) Murray, Nich. *Jour.*, 8vo, i. p. 241, or *Syst. Chem.*, i. p. 320. (*g*) Trail, Nich. *Jour.*, xii. p. 137. (*h*) Thomson, *Syst. Chem.*, i. p. 93. (*i*) Brewster, *Phil. Trans.*, 1816, p. 106, or *Encyclop.* p. 675.

§ 3. *Conducting Power of Gases.*

(219.) With regard to the conducting power of aerial fluids, in the sense to which we have hitherto applied it, we are inclined to think that nothing at all is at present known. Count Rumford supposed them not to possess conducting power at all. If, however, we were to speak of *permeability* we arrive at the actual subject of the last Chapter, Radiation; for in this sense, the gases are highly permeable, as we have shown. The experiment made by Sir Joseph Banks and others, by venturing into a room heated to the temperature of 260°, and remaining there some time, must prove that in such a practical case as is an extremely bad conductor. Water at a much lower temperature would not have been tolerable. Gases

Experiments towards ascertaining the conducting power of gases have been made by Mr. Dalton, Sir H. Davy, and perhaps by others. They ascertained the times of cooling required for thermometer bulbs placed in different airs. But a little consideration will teach us, that this mode of cooling does not apply to our present question, because many other incidental causes must have interfered with the results, or, in truth, the whole investigation refers to radiation. How can we separate the effects due to that action? or how much are we to allow for the circulating currents in the gases? These questions it seems impossible to answer, and without an absolute correction could be obtained for these disturbing causes, we feel that the real question at issue remains quite undecided.

Although perhaps the effect of currents might be guarded against, as in the case of liquids, yet we do not see how the process of radiation is to be prevented in media of such tenuity; and no experiments had until very recently been made, enabling us to ascertain how much of effect might be ascribed to conducting power, after subtracting the effect due to radiation under similar circumstances in vacuo.

We terminate this Chapter with the following passage from Dr. Murray.

"In concluding this subject, it may be observed, that it is principally by the agency of fluids, elastic and non elastic, that the distribution of caloric over the globe is regulated, and great inequalities of temperature guarded against; and that this agency is exerted chiefly by the circulation of which their mobility renders them susceptible.

"Thus the atmosphere, with which the earth is surrounded, serves the important purpose of moderating the extremes of temperature in every climate. When the earth is heated by the sun's rays, the stratum of air reposing on it receives part of its caloric, is rarified, and ascends. At the same time, from a law which attends the rarefaction of elastic fluids, that they become capable of containing a larger quantity of caloric at a given temperature, as they become more rare; this heated air, though its temperature falls as it ascends, retains the greater part of its heat; its place at the surface is supplied by colder air pressing in from every side; and, by this constant succession, the heat is moderated that would otherwise become intense. The heated air is by the pressure of the constant ascending portions, forced towards a colder climate; as it descends to supply the equilibrium, it gives out the heat it had received, and this serves to moderate the extremes of cold. There thus flow a current from the poles towards the equator, at the surface of the earth, and another superior current from the equator to the poles; and though the directions of these are variously changed, by inequalities in the earth's surface, they can never be interrupted, but produced by general causes must always operate, and preserve more uniform the temperature of the globe. Water is not less useful in this respect in the economy of nature. When a current of cold air passes over the surface of a large collection of water, it receives from it a quantity of caloric; the specific gravity of the water is increased, and the cooled portion sinks. Its descent forces up a portion of warmer water to the surface, which again communicates a quantity of caloric to the air passing over it; and this process may be continued for a considerable time, proportioned to the depth of the water. If this is not very considerable, the whole is at length cooled to 40°, below which, the specific gravity not increasing, the circulation ceases, and the surface is at length so far cooled as to be covered with ice. If the depth is much greater, the application of the cold air may be continued longer without this result; and in this, and other countries not intensely cold, it often happens that deep lakes are not frozen in the course of the winter. The depth of the ocean being greater, and the body of water larger, while from its saline impregnation, its points, both of freezing and maximum density, are lowered; it resists freezing still more effectually, and is scarcely frozen indeed, except in latitudes where the most intense cold prevails.

"The quantity of caloric thus communicated by water is exceedingly great. 'The heat,' Count Rumford remarks, 'given off to the air by each superficial foot of water, in cooling one degree, is sufficient to heat an incumbent stratum of air 44 times as thick as the depth of the water, 10 degrees. Hence we see how very powerfully the water of the ocean, which is never frozen over except in very high latitudes, must contribute to warm the cold air which flows in from the polar regions.' From this cause, currents must exist in the ocean similar to those formed in the atmosphere. The water, which in the colder regions is cooled at the surface, descends, and spreading on the bottom of the sea, flows towards the equator, which must produce a current at the surface in an opposite direction; and thus the ocean may be useful in moderating the excessive heats of the torrid zone, as well as in obviating the intense colds of the polar climates." (*a*.)

References for (219:)

Consult (*a*) Murray's *Syst. Chem.*, i. p. 326; Rumford's *Essays*, ii. 417; Berthollet's *Chemical Statics*, i. p. 465; Dalton, *New Syst. Chem. Phil.*, p. 117; *Phil. Trans.*, 1775, p. 111 and 484; Davy, *Phil. Trans.*, 1817, p. 60.

CHAPTER V.

ON THE SPECIFIC CALORIC OF BODIES.

Heat.

(220.) It is found that if a number of bodies of the same initial temperature, be so disposed that they may each receive equal quantities of caloric from some extrinsic source, the heating effects produced upon each of them are not equal. That is to say, equal quantities of caloric, when communicated to different bodies, do not produce equal increments of temperature upon the thermometric scale. Or, if heat be communicated to several bodies, so that they shall all at length manifest the same apparent temperature, the quantities which they are severally found to have imbibed are dissimilar.

This will appear more familiar by an example. Let 1 pound of mercury at 40° Fahrenheit be mixed with 1 pound of water at 156°, and it will be found that the temperature after mixture is about 152°.3 Fahrenheit. Now as the quantities are equal, it might possibly have been expected that the temperature after mixture should be the mean of the temperatures of the substances mixed, or $\frac{156 + 40}{2} = 98^\circ$. By the result, however, it appears that the water has only lost 3°.7 of temperature, which being added to that of the mercury, has raised its temperature 112°.3. But the ratio of 112°.3 to 3°.7 is that of 30.35 to 1. Hence, we say, the specific heat of water is to that of mercury, estimated in equal weights, as 30.35 to 1.

Again, conversely, let 1 pound of water at 40° Fahrenheit be mixed with 1 pound of mercury at 156°: the calculated mean would be 98° as before, but the observed temperature of the mixture is found to be only 43°.7. Here the water has only gained 3°.7, but to supply this, the mercury has lost 112°.3. By which result we arrive at the same ratio as before.

By this or other modes of experiment, bodies are found to differ greatly in the ratios of their *specific caloric*. If instead of employing in this comparison the weights of bodies we make use of their volumes, a different series of ratios is of course obtained. But in general the weight of the substances has been considered in preference to their volume, as being more capable of accurate admeasurement. Tables of both sorts have however been drawn up, and the numbers of the one sort are easily reducible to those of the other, as circumstances may require. Experiments of this nature have been diligently made, with the hope of discovering some general connection existing between this and other physical properties of bodies. The research was long a fruitless one, but by the introduction of the atomic theory, a clue seems to have been found and certain properties discovered, which, should they receive full confirmation, will stand among the most successful instances of philosophical generalization. From these general views we obtain the following definition.

Def. The *relative specific caloric* of bodies, sometimes also called their *relative capacity for heat*, is described by a numerical series, expressing the ratios of the different quantities of caloric necessary to be communicated to, or abstracted from, a given weight, or a given volume of each substance, in order to produce in it a given change of temperature.

Some writers have endeavoured to obtain an expression for *absolute specific heat*, the expression, however, necessarily requires the assumption of some measure of effect; to this subject we shall recur hereafter.

(221.) As an illustration of this definition, we have shown in the last Article that the specific caloric of water is to that of mercury (referring to equal weights) as 30.35 to 1, which is as 1 to .033. Similarly the capacities of other bodies may be compared with that of water; and if we always express its capacity by unity in these comparisons, we obtain a series of ratios having the capacity of water for the unit of the scale.

(222.) It is obvious that this question may be applied to substances under three distinct views.

1. When the substances to be compared are chemically dissimilar, but have all the same initial temperature.

2. When the same substance is considered at different temperatures, though in the same physical state.

3. When the same substance is considered, but under changes in its physical condition.

In attempting to give a succinct abstract of the researches of philosophers into the two first cases simultaneously, a chronological order may be preserved with convenience; while all that relates to the third case, or, as it is termed, the doctrine of *latent heat*, may be reserved for a similar, but independent mode of continuous description.

Method of Mixtures.

(223.) It would appear that Boerhaave was the first to infer from experiment that caloric is not distributed to bodies in proportion to either their density or their volume (*b*,) and some researches were made by Fahrenheit under his direction. The conclusions, however, at which he arrived were quite erroneous, and it is to Dr. Black that we are indebted for the first accurate views upon this subject. In his lectures at Glasgow between 1760 and 1765, he taught that the specific heat of bodies differed. (*c*.) Dr. Irvine pursued the subject between 1765 and 1770. (*d*.) About this time Wilcke of Stockholm applied himself to these investigations, and quotes Klingenstjierna as the author who first recognised the difference between the specific heats of bodies. Professor Thomson, however, states that the late Professor Robison had told him that Wilcke's information was originally obtained from a Swedish whence $(c) = \frac{m\,c\,(T - t)}{(m)\,(t' - T)}$

and the formula sought $\frac{(m)\,(c)}{c} = m \cdot \frac{T - t}{t' - T}$

In a series of experiments this, however, admits of further simplification; for as the expression for the effect of the vessel is constant in a comparative series of results, we may by using the same vessel for several experiments save some trouble, for though in this case the mass of the water m, may vary in each experiment, yet the mass of the vessel (m) remains constant, and therefore the value of $\frac{(m)\,(c)}{c}$ in a series of experiments so conducted will be constant. Hence in each experiment it will only be necessary to add to the mass of water m a constant correction obtained from the substitution of the actual values of (m) (c) and c. This addition will of course be made in terms of that unit of weight to which m refers. And hence in order to a correct result, as much of the heated water is to be made use of beyond the nominal quantity, as will give to the vessel its due share of heat, which otherwise would be stolen from the purposes of the experiment.

M. Biot has selected an example from the experiments of Crawfurd. He put 40 ounces of water, temperature 20°.0833 centigrade, into a tin vessel which itself had a temperature of 42°.916. The common temperature when established was 20.555. Here $m = 40$ ounces; $t = 20.0833$; $t' = 42.916$; $T = 20.555$; m refers to English ounces; and hence (c) might be determined by substitution of values.

But it has been shown that the value of $\frac{(m)\,(c)}{c}$ a constant quantity is sufficient for our purpose, and from the formula

$$\frac{(m)\,(c)}{c} = m \cdot \frac{T - t}{t' - T}$$

By substitution $= 0.84$

that is to say, the vessel takes up as much heat from the experiment as will require to be compensated by an additional 0.84 of an English ounce of hot water.

In order to heat the tin vessel equally in Dr. Crawfurd's experiment, it was fitted exactly into a similar vessel of tin, which was then plunged into a water bath until the full effect had taken place, and the temperature of the bath was of course estimated by a thermometer.

(230.) Another source of error in this method of mixtures arises from the loss of temperature between the instant at which the mixture is made, and that at which uniformity of temperature is established and measured. Crawfurd endeavoured to obtain a correction for this error by observing the law of progressive cooling of the mixture for some time, and thence obtaining by calculation a correction to be added to the observed value T, to make up for the loss. This, however, is a matter of great difficulty and delicacy; and even were the operation easy, there is no certainty that the law of increment is the same for the mixing, as for the mixed substances.

Method by melting of Ice.

Calorimeter

(231.) We now proceed to the experiments of M. Lavoisier in 1777, and those made in conjunction with M. Laplace, and published in 1780. (*f.*) In these a new instrument and a new method of investigation were adopted. This method consists in employing the heat to be given out by the body, for the liquefaction of ice. The water thus obtained is the measure of the heat produced. This method was employed by MM. Lavoisier and Laplace, and the *calorimeter* contrived for these experiments has been already described in article (150.)

It may be well to remark, that the principle of this instrument chiefly consists in the influence of the exterior case of ice contained between the two metallic vessels A B C D, A′ B′ C′ D′, fig. 18; for it is that envelope which by its presence continues the temperature of the ice within at zero C°, and hinders it from fusing, except by the action of the body introduced within its central space.

Suppose this body a solid, and of a nature not to change its state between the temperature of melting ice and boiling water; then having brought it to any temperature t comprised between these limits, and measured in degrees of the mercurial thermometer; let it be placed in the calorimeter, and left to cool down to 0° C. Arrived at this point we shall find that the quantity of ice which it has melted, is proportional to the number of degrees t; so that if in cooling from 10° to 0° it has melted 1 kilogramme; it will in passing from 20° to 0° melt 2 kilogrammes, and 3 in cooling from 30° to 0°, and so on throughout the thermometric scale. But the constancy of this ratio will be different for different bodies of the same given mass. For example, if a certain weight of sheet iron heated to 30° has fused 11 kilogrammes of ice, the same weight of mercury raised to the same temperature will only fuse 3 kilogrammes. Quantity is here an essential element; for a double or triple mass of the same substance melts a double or triple quantity of ice under the same circumstances.

That we may form a clear idea of these results, and deduce accurate consequences from them, let us take for the unit of caloric the unknown quantity of that principle which is requisite to fuse a kilogramme of ice at 0°; and let x represent the total and unknown number of such units, which at the temperature of melting ice are contained in each kilogramme of a body A, in whatsoever mode that caloric may exist, whether fixed and in combination; or free and capable of undergoing change by radiation with other bodies in free space; or even by portions in all these different states. If now we raise the temperature of A to T degrees on the mercurial thermometer, and then leave it to cool to 0° in the calorimeter, there will be melted a certain number of kilogrammes of ice, which we may represent by N; then, according to our previous assumption, N expresses also the new quantity of heat necessary to be introduced into the body to elevate its temperature to T°. But experiment proves that between 0° and 100° the number N is proportional to the number T of degrees, at least as long as the body does not change its physical state. Consequently, if we divide N by T, the quotient $\frac{N}{T}$, which we may call c, will express between these limits the number of kilogrammes of ice which the body is capable of melting in lowering its temperature one degree; and the same quotient will express also in terms of our primary unit, the quantity of caloric necessary to raise or lower its temperature

As these numbers are so constantly referred to for comparison with other substances, we shall do well to remember, that the *absolute specific heat* of water equals unity divided by the temperature of that water which just melts an equal volume of ice. And that this result comes out in degrees of whatever scale may be used for the estimation of the temperature.

(233.) If we divide the absolute specific heats of bodies estimated on either scale by these quantities respectively, we shall obtain the series of relative specific heats, referred to that of water adopted as the unit of the scale. But in order that we may repass from these values to absolute results, it is always necessary to include the absolute specific heat of water. The following are a few results of this sort given by Lavoisier and Laplace:

Common water	1.00000
Sheet iron	0.11051
Glass without lead	0.19290
Mercury	0.02900
Red oxide of mercury	0.05011
Lead	0.02819
Red oxide of lead	0.06227
Tin	0.04754
Sulphur	0.20850
Olive oil	0.30961
Quick lime	0.21689

According to the signification which we have attributed to the coefficient c, the ratios contained in this table may immediately serve to estimate numerically the transfer of heat from one substance to another included therein. Thus the number 0.029° corresponding to mercury, shows that a mass of mercury in cooling 1° gives out a quantity of caloric sufficient to raise the temperature of an equal mass of water 0.029°. A mass of quick lime in cooling 1° might raise the temperature of an equal mass of water, 0.21689°. Hence it follows, that the caloric given out by a mass of mercury in cooling 1° would be equal to elevate the same mass of quick lime $\frac{0.029}{0.21689} = 0°.134$. Here the scale on which the degrees are counted is unimportant, because it is the same in both valuations.

(234.) Moreover, if we multiply the numbers of this table by $\frac{1}{60}$, which expresses the absolute specific heat of water in degrees of Reaumur, we shall have the weights of ice which one unit weight of each of these substances could melt in cooling through 1° upon that scale. If we made the multiplication by $\frac{1}{75}$ or $\frac{4}{300}$, we should obtain the analogous result for 1 centesimal degree. These then would be the *absolute* specific heats of the substances included in the table. For example, dividing thus the number 0.66139 (which belongs to nitrous acid) by 60, we again find the number 0.010232 which we obtained before as the absolute value of its specific heat.

(235.) It seems that mercury has a very low degree of specific heat. To raise the temperature of this liquid 1°, there only requires $\frac{29}{1000}$ of that which a mass of water of equal weight would require. The almost absolute constancy of the value of c for mercury throughout that part of the thermometric scale between the freezing and boiling of water is a fact worthy of notice; for it hence follows, that within those limits the quantities of heat introduced into that substance are justly proportional to the elevation of temperature measured in degrees upon the scale. But these degrees themselves are measured by the dilatations of the mercury, and are proportional to those dilatations; therefore the dilatations of mercury within the limits of the thermometric scale are proportional to the increments of caloric received.

(236.) It were unjust to pass by the name of Crawfurd without acknowledging him to have been one of the most laborious and praiseworthy experimentalists in this department of science. The objects to which his researches tended were of first rate importance, for he thought that he had obtained an elucidation of the source of animal heat, by investigating the changes of capacity which attended the effects of respiration upon the blood. In 1788 his *Essay on Animal Heat* appeared, and though the whole foundation of his reasoning has been proved to be unstable, yet the numerous experiments which he made upon the specific heats of bodies were conducted with great care, and are still justly regarded with interest. (*g.*)

Meyer's Process.

(237.) About this time Meyer devised another process for comparing the specific heats of bodies. The times were observed, which were requisite to cool down equal volumes through a given interval on the thermometric scale. These times were considered to be as the capacities directly. But of course this estimation is referred to volume, so that if we wish to deduce the specific heats with reference to mass, we must divide the numbers thus obtained by the specific gravities of the substances respectively.

$$\text{Hence Sp. Cal. by mass} = \frac{\text{Sp. Cal. by vol.}}{\text{S. G.}}$$

This method is highly approved by Professor Leslie, who recommends it strongly in his interesting work upon heat. (*m.*) There is also the authority of Mr. Dalton in its favour, who conceives that it has an advantage over the method of mixture, being independent of any inaccuracy in the mercurial thermometer. (*n.*) This method seems chiefly adapted to substances in the liquid form; but the following remarks upon it by the late Mr. Murray are not unworthy of attention. "The principle however, on which it rests, is not just; for the cooling of bodies depends on other circumstances than their capacities. It is influenced both by their radiating and conducting powers. Any error indeed from the former, may be avoided by the mode in which the experiment has been performed by Leslie and Dalton, giving the same external surface to the body while cooling, by including it in a glass globe. But it is not possible entirely to obviate the latter. It is obvious, in the example of a mass of matter at a high temperature, communicating the excess of its heat to the surrounding medium, whether by the intervention of a vessel containing it, or not, that if it be an imperfect conductor of caloric, the caloric passing more slowly from the internal mass to the surface, the time portion for the difference between the temperatures of the calorimeter and the tube.

The method of determining by means of ascending and descending series, the maximum temperature which each current of gas would communicate to the calorimeter, has been already described; but as it would have been tedious to obtain this maximum by the sole influence of the current of gas, the calorimeter was brought nearly to that point, by applying the heat of a small spirit of wine lamp; the action of the gas was then allowed to proceed until the slowness of the heating or the cooling of the calorimeter showed that the maximum effect was not distant more than three or four tenths of a degree. This difference, though small, was nevertheless very perceptible in the experiments; for the temperature of the calorimeter was measured by a thermometer, on the scale of which one centesimal degree occupied a length of ten millimetres, which permitted the measurement of tenths and the estimation of hundredths of a degree. This thermometer had a cylindric reservoir, in length equal to the depth of the calorimeter, so that it accurately measured the mean temperature of the various strata of water contained in it.

It was essential to determine most accurately the temperature of the current of gas at its entrance into the calorimeter. This temperature was always rather below 100°; for however short the glass conducting tube might be, we may easily suppose that the gas must cool a little in passing through it. To estimate that cooling, a very sensible thermometer was placed within the tube itself, at the point where it entered the calorimeter, and this thermometer continued steadily between 95°.6, and 92°.6, according to the nature of the gas. But certain trials proved that the temperature thus indicated was always rather inferior to that of the gas itself; and as that temperature could not possibly exceed 100°, it seemed not far distant from the truth to take the mean of these two values, that is to say, to consider the temperature of the gas as intermediate between 100°, and the temperature indicated by the thermometer in the tube. Another thermometer, placed at the very point from which the gas issued, proved that it escaped exactly at the temperature of the water contained in the calorimeter.

Finally, it remained to bring all the results into a comparable state; for it was of course physically impossible to operate always upon gases at the same temperature and pressure, even if there were no other cause beyond the ordinary changes of the atmosphere. With this view the authors made two auxiliary experiments upon atmospheric air, under different pressures. These pressures were easily obtained by means of the gasometers employed. It was only necessary to alter the height of the tubes which permitted the introduction of air into the vessels. In an experiment of this sort, the gasometers were so adjusted, as to give a pressure of $1^{m}.0058$; for, to the natural pressure of the atmosphere, which was $0^{m}.7527$, there was an additional one of a column of water, $3^{m}.44$ in height, equivalent to $0^{m}.2531$ of mercury. The current was such as to convey in 10 minutes through the calorimeter 31.1 litres of air, taken originally at the temperature 5°; which is equivalent to $30^{l}.53$, if taken at 0° originally. This current, heated to 100°, and then employed as in the other experiments, raised the temperature of the calorimeter to 16°.117 above the surrounding air; the heat communicated by the conducting tube being properly deducted. This air entered the calorimeter at 96°.90; it issued at 22°.832; therefore it suffered a depression of temperature of 74°.068. Let C be the total quantity of heat disengaged from it; and if we suppose that the specific heat of each gas remains constant throughout the range of the thermometrical scale, when the pressure is constant, it is clear that *one litre* of air, under a pressure of $1^{m}.0058$, as in the present case, and cooled in a similar manner, would have disengaged $\frac{C}{30.53}$ being in proportion to its mass; whence it follows that it would only have disengaged $\frac{C}{30.53 \times 74.068}$ in cooling down 1°. But we have seen that the quantity C is proportional to the permanent excess of the temperature of the calorimeter above that of the surrounding air. Therefore that excess may be taken for the measure of the heat disengaged, representing it by the number of degrees of the thermometer to which it corresponds: then the actual value of C will be 16°.117, and the number $\frac{16.117}{30.53 \times 74.068}$ or 0°.0071274 will express the elevation of temperature at which the calorimeter may be maintained by the passage of one litre of air, taken originally at the temperature of 0°. C, under a pressure of $1^{m}.0058$, and cooled at 1°. But in another experiment, made at a pressure of 0.7405, it appeared that $35^{l}.99$ of air measured also at 0° in cooling through 72°.415, had continued the elevation of the calorimeter at 15°.423, which by a similar mode of calculation gives $\frac{15.423}{35.99 \times 72.415}$ or 0°.00591778 for the quantity of heat disengaged under these new conditions, by one litre of air cooling one degree. Dividing the former result by the latter, we have $\frac{0.0071274}{0.00591778} = 1.20441$ for the ratio of the quantities of caloric disengaged by two equal volumes of air, at equal temperatures when the ratio of the pressures is $\frac{1.0058}{0.7405}$ or 1.35827. A series of similar experiments gave for the mean ratio of the quantities of caloric 1.2396 instead of 1.20441. So that a variation of 0.35827 in the density, produces only a variation of 0.2396 in the quantities of caloric. Now, let us suppose a given volume of air, taken at a pressure p, has disengaged a quantity of heat C, measured by the number of degrees which it raises the temperature of the calorimeter above that of the air; if we represent the number of degrees which the same volume of air would have produced under the same circumstances as to temperature, but under some other pressure p', by the quantity C $(1 + z)$; we may by a sufficiently near approximation suppose the proportion

$$0.35827 : 0.2396 :: \frac{p' - p}{p} : z$$

whence

$$z = 0.2396 \frac{p' - p}{p.0.35827}$$

Thus did our authors proceed, and they were the more justified in doing so, because all their experiments took place under the natural pressure of the atmosphere, and therefore presented but slight variations of pressure. We perceive also from the same reason, that the assumption of the constancy of the specific heats could not produce any appreciable error in the reduction;

To deduce the second column from the first, the specific gravities are employed which are given in p. 381, book i. Biot's *Physique;* the specific heat of the vapour of water was obtained by comparing the cooling of the calorimeter effected by dry air, with that produced by air saturated with moisture at a temperature of 40°. This required that the atmosphere surrounding the calorimeter should be kept rather above that temperature, in order that no precipitation of vapour might take place; for the great evolution of caloric that must accompany any such precipitation, would have produced very considerable error in the result.

These results are only relative. To make them absolute, we must obtain the actual value of some one among them; that is to say, we must ascertain for some one gas, atmospheric air for example, the quantity of ice which a given volume, under a given pressure, is capable of fusing by cooling down 1°; or which is the same thing, the quantity of water which it would boil; or, lastly, the increment of temperature which it could produce in a given mass of water. But the last result may be deduced from the experiments themselves. In fact we know the weight m of water contained in the calorimeter, as also the mass of the sheet copper and the solder of which it is made. The copper, according to Crawfurd, has a relative specific heat of 0.112; and solder, an alloy of lead and tin, may be considered as having a specific heat intermediate between those of its two metals, that is of 0.038. From these data we may calculate the number of grammes of water to which the sides of the instrument are equivalent; and adding this to the mass m, we have $m + \mu$, the grammes of water represented by the whole instrument. Here the number was $596^g.8$. But in the first experiment above cited $35^l.99$ of air, measured at 0° C, and under a pressure $0^m.7405$, if heated to 100°, produced a current which in cooling down 72°.415 maintained the calorimeter stationary ten minutes at a temperature of 15°.734 above the surrounding air; whence it follows, that such a current then furnished to the calorimeter just as much heat as it lost to the surrounding air. This loss it is easy to estimate; for we have only to stop the current of gas, and allow the calorimeter to cool spontaneously, and observe the law of its refrigeration, calculate the logarithmic curve that represents it, and obtain from the formula the initial velocity of refrigeration. In fact if we call $(y) + \mathrm{T}$ the initial temperature of the calorimeter, (y) being that of the surrounding air, and find that after t minutes the former quantity is reduced to $(y) + y$ we know that the law of cooling will be

$$\log y = \log \mathrm{T} - \frac{a}{\mathrm{M}} t.$$

In this formula M is the modulus of the common logarithmic tables, or 2.302585; and the coefficient a, as in electric experiments, expresses the proportion of refrigeration in the unit of time; that is to say, the number of degrees which the refrigeration would take away from a body continued during that whole time at an elevation of 1° above the temperature of the surrounding air. This proportion from the nature of the law remains the same as long as the refrigeration continues.

If we wish to ascertain the effect upon the initial temperature T, we must obtain the value of $a\,\mathrm{T}$ from our equation: thus

$$a\,\mathrm{T} = \frac{\mathrm{M\,T}\,(\log \mathrm{T} - \log y)}{t}$$

Whence we perceive that this value is known when we know, in addition to the initial value of T, any single value of y observed after any time t. But in the experiment on atmospheric air, above mentioned, Delaroche and Berard had at first the initial excess $\mathrm{T} = 15°.734$; and by a subsequent observation they found $t = 20$ minutes, $y = 12°.847$;

$$\text{whence } a = 0°.0101365, \text{ and } a\,\mathrm{T} = 0°.159474.$$

Knowing that the number of degrees communicated to the calorimeter by the gas in one minute, we have for 10′ ten times that quantity = 1°.59474; a similar series of experiments gave 1°.5996. But the $35^l.99$ of air employed to produce the current weighed $45^g.49$, as may be calculated from the data in Biot, *Phys.*, book i. p. 387; and the effect produced was upon $596^g.8$ of water, by the air cooling down 72°.415. The relative specific heat of air, under the pressure above mentioned $= \dfrac{596.8 \times 1.5996}{45.49 \times 72.415}$ or $= 0.2898$.

Other processes gave results almost exactly identical, though always rather inferior. By taking a mean, and reducing the effects to what they would have been if the refrigeration had taken place under a pressure of $0^m.76$, the authors decided upon the number 0.2669, as representing (under that pressure) the specific heat of air referred to water as unity. By multiplying all the relative specific heats obtained for a given weight of each gas, by this common factor, they obtained the following table:

	Specific Heat.
Water	1.0000
Atmospheric air	0.2669
Hydrogen gas	3.2936
Carbonic acid gas	0.2210
Oxygen	0.2361
Azote	0.2754
Oxide of azote	0.2369
Olefiant gas	0.4207
Oxide of carbon	0.2884
Watery vapour	0.8470

Each of these results expresses the elevation of temperature which one gramme of each gas would produce in one gramme of water, by itself cooling one centesimal degree. By dividing each number by 75 we obtain the number of grammes of ice at 0° which the same refrigeration could melt; and by dividing them by 100, we obtain the number of grammes of water which it would bring from the temperature of melting ice to that of ebullition.

It must be remarked, however, that these results are the expressions for a very complicated phenomenon. By the method in which the experiments are made, the gases contract as they cool, since they have to become always equivalent to the same pressure; and thus their density, when they enter into the calorimeter, is less than when they issue from it. The calorific effect then which they produce upon that instrument, is the effect compounded of the heat which they disengage both in cooling, and in contracting at the same time; instead of which, in order to obtain the simple results, we ought to be able to observe these effects separately; first having determined the quantity of heat which each gas disengages in cooling down within a given space, and of course under a constant volume; and then also the quantity which it disengages, when its volume changes, the exterior temperature remaining constant. The separation of these two phenomena appears extremely difficult; but it is indispensable, in order to obtain simple results, and to investigate the exact laws which regulate these operations. A similar inconvenience presents itself in experiments upon the specific heats of liquid and solid bodies, as they also necessarily contract as they cool; but as the variation of their volume is much less considerable, we may suppose that the evolution of heat which it occasions is also very small, compared with that which arises from the diminution of temperature. (*s*) and (*cc.*)

(241.) The question of capacity, as referring to gases and vapours, has been submitted to mathematical analysis by M. Laplace in the XIIth Book of the *Mécanique Céleste*, and perhaps still more successfully and comprehensively by M. Poisson. (*z.*) For these investigations, which are not susceptible of abridgement, we must refer to the original memoir; but as it may be a matter of convenience to some to have the formula at hand, we here subjoin those which are of practical utility.

$$\left\{ q = \mathrm{A} + \mathrm{B}\,(266.67 + \theta)\; p^{\frac{1}{k} - 1} \right\}$$

$$\left\{ \frac{m'}{m} = \left(\frac{p'}{p}\right)^{\frac{1}{k}} \right\}$$

The former expresses the augmentation of heat of a gas, and the latter the ratios of the quantities of heat lost by a gramme of air, θ being the number of centigrade degrees, p and p' the pressures for a unit of surface, A and B constant coefficients, and k a coefficient which varies for different gases, which has been found $= 1.3750$ for atmospheric air, by MM. Gay Lussac and Welther, and which expresses the ratio of specific gravity, under a constant pressure, and at a constant volume.

In the second paragraph, M. Poisson applies the first of the above formulæ to the vapour of water, C being the quantity of heat necessary to reduce to vapour a gramme of water under a pressure of 76^{m}, at the temperature 100°, the formula then becomes,

$$q = \mathrm{C} + y \left\{ (266.67 + \theta) \left(\frac{0^{\mathrm{m}}.76}{h}\right)^{\frac{k-1}{k}} - 366.67. \right\}$$

The coefficient C has been found $= 650$; the coefficient $y = 0.8470$, according to MM. Delaroche and Berard; and as to the coefficient k, it has been found by remarking that the quantity of heat contained in each gramme of vapour is sensibly the same at all temperatures, when a certain space is saturated with vapour; thus it has been found, that when $\theta = 50°$, the tension of the vapour $\mathrm{H} = 0^{\mathrm{m}}.088742$, whence it appears that by substituting this value for h, and making the coefficient of $y = 0$, $k = 1.073$. The author then refers to this formula, that which expresses the quantity of heat necessary to form a volume V of vapour at the temperature θ, and at the tension h; it is $\mathrm{V} = \frac{h \,.\, v}{0^{\mathrm{m}}.76} \, \frac{187.33 \,.\, \mathrm{Q}}{266.67 + \theta}$; and it shows that the quantity Q does not undergo an appreciable variation for steam engines.

In the third paragraph, the author considers the mixture of two gases, of which the volumes n and n' are different, filling a volume v at the temperature θ; c and c' being the specific heats of a gramme of these gases under a constant pressure p, c'' the specific heat of the mixture, $c_{\prime}$ $c_{\prime}'$ and $c_{\prime}''$ representing the same specific heats respectively under a constant volume, k k' and k'' the ratios of the former specific heats to the second ones; the author deduces this formula,

$$k'' = \frac{n\,k\,c_{\prime} + n'\,k'\,c_{\prime}'}{n\,c_{\prime} + n'\,c_{\prime}'}$$

from which it appears that the ratio k'' with reference to the mixture is not independent of the pressure p, and that therefore the same formulæ do not apply both to simple gases and mixtures of gases, this ratio not being apparently constant, except for air and the vapour of water.

Dr. Ure.

(242.) In order of time we next find some experiments on the specific heat of a few liquids made by Dr. Ure, throughout a considerable range of temperature. Of these we shall give the author's own description, abstracted from his paper on muriatic acid. (*x.*)

"A thin glass globe, capable of holding 1800 grains of water, was successively filled with this liquid, with strong muriatic acid S. G. 1.192, and with that of S. G. 1.152; and being in each case heated to the same degree, was suspended with a delicate thermometer immersed in it, in a large room of uniform temperature. The comparative times of cooling through an equal range of the thermometric scale were carefully noted by a watch in each case. The following were the results:

Globe, with	water cooled from	124°	to 66°	Fahrenheit, in 122	minutes.
Ditto	dilute acid......	124	to 66	 102	do.
Ditto	strong acid	124	to 66	 88	do.

"The glass itself had a capacity for heat equal to that of 150 grains of water. Hence in the three cases we have the following relations between the quantities of matter cooled and the times of cooling:

$$\text{Water} \ldots\ldots\ldots \frac{122' \times 100}{1800 + 150} = 62'.6$$

$$\text{Dilute acid} \ldots \frac{102' \times 100}{2020 + 200} = 46'$$

$$\text{Strong acid} \;..\; \frac{88' \times 100}{2154 + 250} = 36'4$$

"If water be called unity, or 1.000, then the dilute acid is 0.735, and the strong acid is 0.586. These numbers represent the specific heats by experiment. But the dilute acid ought, from calculation, to have the mean capacity for heat, corresponding to 6 strong acid + 4 of water $= \frac{6 \times 0.586 + 4 \times 1.00}{10} = {\cdot}7516.$

We see, therefore, that the capacity is diminished in the ratio of .735 to .7516, to which cause the evolution of heat is due.

"Conceiving that I observed in the successive stages of cooling of the several liquids indications of the relative specific heats, varying at different temperatures, I made the following experiments to decide this interesting point. The same glass globe and thermometer were employed.

Water cooled from............	210° to 150°	in 21'.5	and from 150° to 90°	in 57'
Concentrated oil of vitriol	210 to 150	in 17.0	and from 150 to 90	in 30¼
Spermaceti oil, S. G. 0.915....	210 to 150	in 12.75	and from 150 to 90	in 29
Oil of turpentine, S. G. 0.875..	210 to 150	in 11.25	and from 150 to 90	in 25.83

Hence, including the specific heat of the vessel, and the difference of density of the liquids, we get the following equations:

	Upper range.	Under range.
Water	$\frac{21'.5}{1.950} = 11'$	$\frac{57'}{1.950} = 29'.2$
Sulphuric acid	$\frac{17'}{3.695} = 4'.6$	$\frac{39.33}{3.695} = 10'.64$
Spermaceti oil	$\frac{12'.75}{1.940} = 6'.57$	$\frac{29'}{1.940} = 15'.0$
Oil of turpentine	$\frac{11'.25}{1.875} = 6'.0$	$\frac{25'.83}{1.875} = 13'.8$

"And reckoning water unity,

	Upper range.	Under range.
Water..............	1.000	1.000
Sulphuric acid	0.418	0.364
Spermaceti oil	0.597	0.513
Oil of turpentine	0.545	0.472

"The ratios of the sulphuric acid and of the two oils are obviously proportional to one another in both ranges; but the specific heat of the water, compared with these bodies, increases in a remarkable ratio as its temperature falls. Had I continued the experiments to still lower degrees of the thermometer, this difference would probably have become greater. But when the substance operated upon approached the temperature of the atmosphere, which was then from 55° to 60° Fahrenheit, the cooling was too slow to permit the intervals of time to be marked with the requisite precision.

"Hitherto the specific heats of bodies have been compared with that of water, either at the freezing temperature, as in the calorimeter of Lavoisier and Laplace, or by admixture, or rate of refrigeration at very moderate heats. In all these cases the capacity of water, being at a maximum, has caused other bodies to stand relatively low upon the capacity scale. The mean capacity of water, between that of freezing and boiling, is probably to be placed at about the hundredth degree of Fahrenheit's scale.

"By thus possessing at ordinary atmospherical heats its maximum specific caloric, water is peculiarly fitted for performing its important function of a magazine and equalizer of temperature to the terrestrial globe." (*x*.)

Dulong and Petit.

(243.) Proceeding towards the close of this branch of our subject, we have yet one more very important series of experiments to examine. These were made by MM. Dulong and Petit, and published in 1817. In the part which concerns us at present, they refer to the experiments of Crawfurd and De Luc, made with a view to ascertain whether the specific heats of liquids remained constant at all temperatures, measured upon the scale of the mercurial thermometer. Crawfurd convinced himself that there was a slight variation in the capacity of water during the first 100 degrees, while De Luc considered that there was no such variation. Mr. Dalton, who has exerted great labour and ingenuity upon all the doctrines of heat, considered that the capacity of a mass of matter did not remain constant, because one portion of heat is employed in producing dilatation; but that if a given volume were estimated, the capacity might be considered as constant.

This point MM. Dulong and Petit investigate by employing the method of mixtures as in (220) and (224), extending their observations to an interval of from 0° to 350° upon the thermometric scale. The experiments were made upon metals difficult of fusion; wherein the excellence of the conducting power, and the homogeneity of the substances formed additional recommendations. The metals were formed into circular discs, weighing from about 2 to 8 English pounds. The baths employed for the immersion and heating of the metals were of boiling water, boiling mercury, or oil heated to a given temperature. After the metals had been heated in these baths, they were instantly plunged into water, and the temperature thus communicated measured with extreme care. For all the minute details of these experiments we must refer our readers to the memoirs of the authors themselves.

The high capacity of iron compared with other metals, and the power of heating it most accurately in boiling mercury, made them select this substance for their first experiments. The capacity of water is considered unity, and the following table shows the general result of several experiments which accorded well with each other:

Mean specific heat of iron from 0° to 100° = 0.1098
Mean specific heat of iron from 0 .. 200 = 0.1150
Mean specific heat of iron from 0 .. 300 = 0.1218
Mean specific heat of iron from 0 .. 350 = 0.1255

The general result showing in which direction the variation took place in these experiments, is confirmed by the following table, including some other metals:

	Mean specific heat between 0° and 100°.	Mean specific heat between 0° and 300°.
Mercury	0.0330	0.0350
Zinc..........	0.0927	0.1015
Antimony......	0.0507	0.0549
Silver	0.0557	0.0611
Copper........	0.0949	0.1013
Platinum	0.0355	0.0355
Glass	0.177	0.190

It is, then, with the capacities of solid bodies as with their dilatabilities, both increase with their temperatures, as measured upon the air thermometer. They would increase still more if the mercurial thermometer were employed, which is contrary to the opinion of the process of Meyer, pointed out a necessary precaution, of the importance of which Meyer was not aware, that of always enclosing the body in a vessel of one kind of matter, for the sake of avoiding the error arising from inequalities in the radiating power of the surfaces. But of all the sources of error, there is one which it is most important to avoid, and which has not been regarded by either Meyer or Leslie; it is that which arises from the unequal conducting power of the substances compared. The influence of this cause is less in proportion as the volume of the substance operated upon is diminished, and the loss of heat slowly carried on. These two then are important conditions to be observed; but they seem difficult to act upon simultaneously, for by diminishing the mass of any substance, we augment the velocity with which its heat is dissipated. By endeavouring, however, to unite all those causes, which for any given mass conspire to retard the cooling, we may (as experiments have proved) obtain such conditions that the different conducting power of the bodies operated upon shall have no sensible influence upon the estimate of their capacities.

The first method which presents itself for attaining this object, consists in making the experiments, with the substance itself elevated only a few degrees above that of the surrounding bodies. Thus all the experiments referred to hereafter, were made within an interval of temperature comprised between 10° and 5° centigrade of excess above the ambient medium. In this case the utmost nicety in the measure of the temperatures is requisite: for even a slight error in this estimate might occasion a much more serious one in the final result. By making the experiments upon all substances at the same temperature, we avoid all uncertainty arising from the graduation of the thermometer; and by observing that instrument with a lens of considerable power, MM. Dulong and Petit say that they are confident of having no error above $\frac{1}{500}$ of a degree, which cannot produce any appreciable error in the calculated specific heat of the body. It is evident, however, that all these precautions would be insufficient, if the temperature of the surrounding medium were not precisely the same in all cases, and during the whole time of each experiment. This condition, however, was fulfilled, by placing the body in a vessel of very thin substance, blackened within, and covered on all parts with a thick envelope of melting ice.

"To this first mode of retarding the refrigeration, without removing from the admeasurements that precision which they ought to maintain, another is added, the influence of which may be calculated by knowing the laws of the communication of heat. It results from these laws that the rate of a substance cooling, may be *cæteris paribus* much diminished when the surface possesses only a very slight radiating power; and is placed in a highly dilated atmosphere. To comply with these conditions, the experiments were made upon solids reduced to extremely fine powder. In this state they were strongly pressed into a cylindrical vessel made of very thin silver, and of small capacity, having in the axis the bulb of a thermometer serving to indicate the progress of refrigeration. This vessel was then placed in the centre of the enclosure, and the air within dilated to a very slight degree of tension, (about 2 millimetres,) taking care to reproduce exactly the same in each experiment."

By precautions like these, even when the most dense substances, such as gold and platinum were examined, the masses did not exceed 30 grammes (about 9 English ounces,) and in the most rapid instances of cooling the duration was at least 15 minutes.

By comparing the specific heats thus obtained, for substances the worst conductors, with those estimated by the method of mixtures or by the calorimeter, the coincidence of the results gave a very convincing proof of the exactness of the process adopted.

Specific heats. Specific heat of water = 1.		Relative weights of the atoms. Oxygen = 1.	Products of the atomic weight × the capacity.
Bismuth ..	0.0288	13.30	0.3830
Lead	0.0293	12.95	0.3794
Gold	0.0298	12.43	0.3704
Platinum .	0.0314	11.16	0.3740
Tin	0.0514	7.35	0.3779
Silver	0.0557	6.75	0.3759
Zinc	0.0927	4.03	0.3736
Tellurium .	0.0912	4.03	0.3675
Copper ..	0.0949	3.957	0.3755
Nickel ..	0.1035	3.69	0.3819
Iron	0.1100	3.392	0.3731
Cobalt ..	0.1498	2.46	0.3685
Sulphur ..	0.1880	2.011	0.3780

Dulong and Petit, *An. de Ch. et de Ph.*, x. 403.

This table represents the capacities of certain simple bodies, and is limited to those cases, of the accuracy of which the authors felt perfectly convinced. The column expressing the atomic weights (see CHEMISTRY) of the substances, is given for the purpose of bringing forward the very important law which the authors think they have established. By a bare inspection of the table it appears that (allowing for the unavoidable errors of experiment) the capacity of each simple body, multiplied by the weight of the atom, is a constant quantity.

"We may," say they, "by means of this table easily calculate the ratios which exist between the capacities of atoms of different kinds. To pass from the specific heats furnished by observations to the specific heats of the atoms themselves, it is enough to divide the former by the number of atoms contained in a given weight of the substances to be compared. But it is obvious that these numbers of particles are for equal weights of matter reciprocally proportional to the densities of the atoms. Hence our result is obtained by multiplying each of the capacities obtained by experiment by the weight of the corresponding atom. Such are the products contained in the last column of the table. The number and the diversity of the substances we have operated upon do not permit us to consider our results fortuitous, and we think we are authorized to deduce the following law from them.

"*The atoms of all simple substances have exactly the same capacity for heat.*

"By remembering the uncertainty which as yet attends the fixing the specific weights of the atoms, we may easily conceive that the law just established would change the form of its enunciation, if we adopted a supposition concerning the density of the atoms different from that which we have admitted; but under all circumstances this law would involve the expression of a fluid; nay more, nitre where it is in the solid state; produce by their decomposition with combustible bodies, certain quantities of heat, which differ little from that which would be produced by a volume of gaseous oxygen equal in quantity to that contained by the substances. This remark, which ought to have raised a doubt concerning the truth of the fundamental law, only caused a restriction of its generality. It was supposed that in certain combinations oxygen was capable of retaining a proportion of heat almost as great as that which was essential to its constitution as a gaseous fluid. Some facts still more recently observed, seemed even not to be capable of explanation upon that theory, but by admitting that oxygen in some cases of combination, retained a quantity of heat, even superior to that which it possessed in the free state. Such are the detonations produced by mixing chlorate of potash with certain combustibles, or the spontaneous explosions of the euchlorine of Sir H. Davy, and of the chloride and iodide of azote.

"This explanation was subsequently extended to all combinations, and it was regarded as a principle sufficiently established, that one body in combining with a certain number of others, might give out a greater or less proportion of its own proper caloric, according as in each case the different degrees of the affinity of the elements in contact produced a more or less intimate approximation between their molecules. It is the degree (essentially variable) of this approximation, which has been designated by the word Condensation, so frequently employed in the language of chemistry.

"Such is the theory almost universally adopted in France. Some foreign chemists have pointed out its inaccuracy, and have modified it in many points, but without advancing any rigorous proof either against the opinion which they attack, or in support of the one they wish to substitute in place of it.

"We perceive, then, that the different explanations relative to the developement of heat in chemical combinations, are reducible to simple assertions, derived from the first hypothesis of Lavoisier. It is surprising, that since the period which gave rise to that doctrine, no one has exposed it to more severe examinations, and that even from the results already known, all the arguments have not been collected which might have been brought forward against it. We are of opinion, that the relations which these experiments point out between the specific heats of simple substances, and those of their compounds, no longer permit us to suppose that the heat evolved during chemical action only owes its origin to that heat which produces a change of physical state, or to that which we regard as combined with the material molecules. We have the greater reason for rejecting this entirely gratuitous hypothesis, because we are able to explain the phenomenon in a much more satisfactory manner.

"In fact, Sir H. Davy long since showed that by forming a communication between the two poles of a Voltaic pile with a small bit of charcoal placed in a gas unfitted for combustion, this substance may be kept in a state of vivid ignition as long as the pile remains in activity, without the charcoal undergoing the slightest alteration. On the other hand, we may conclude from the extensive series of galvanic experiments made by MM. Hissinger and Berzelius, and also from those of M. Davy, that all substances which do combine, find themselves with regard to each other at the instant of combination exactly in the same electrical condition as the two opposite poles of the pile respectively. Is it not then probable that the same cause which produces the incandescence of the charcoal in the beautiful experiment above cited, is identical with that which to a greater or less degree elevates the temperature of the substances in the act of combination? This is at least a supposition founded upon the strongest analogies, and which deserves to be pursued through all its consequences.

"At the same time we are far from arguing that those changes of physical constitution which result from chemical combinations perform no part in the developement of the heat which accompanies them; we only wish to assert that in the case of very energetic combinations, this cause generally produces only a very small portion of the total effect.

"In terminating this memoir we cannot silently pass by another very important application to which the exact knowledge of the specific weight of the atoms would lead us. If, as we have every reason to hope, we shall arrive by means of the preceding considerations at the determination of that element with certainty, we shall be enabled, setting out with the true densities of bodies, to calculate the ratios which exist between the distances of their atoms: and, it is easy to perceive of what consequence it would be, in the midst of a number of philosophical theories, to be able to establish a comparison between the distances of the atoms, and certain phenomena which it is reasonable to suppose are connected with that new element. It is in examining under this view the question of dilatations, that we may hope to arrive at some simple laws, which as yet are entirely unknown. Some attempts founded upon the observations of different philosophers, and upon some which we had made for a different purpose, have led us to consider it extremely probable, that some very simple relation exists between the dilatability of liquids and the distances of their molecules. The beautiful observation of M. Gay Lussac, of the identity of the contractions of carburet of sulphur and alcohol, setting out from their respective points of ebullition, comes in confirmation of our opinion; for these two liquids present this remarkable peculiarity, that at the temperatures at which they have been compared, the distances between their atoms are almost exactly the same; but previously to the extending those researches which might be made upon this subject, it is absolutely essential that the question of specific heats should be cleared up as much as possible, and that all those consequences to which it may lead, touching the knowledge of the constitution of bodies, should be primarily deduced." (*u*.)

(248.) We are convinced that the importance of the subject, and the novelty of these views, will appear to all our readers a sufficient reason for the length of the above extract. It is true these are but the opinions of two individual experimentalists, but these are well known as of the highest order in ability and research; whether this beautiful step towards generalization may safely be admitted as a fact proved, future researches must decide, and it is with a view to call the attention of English experimentalists to this point, that so ample a view of the question has here been brought forward.

A general table of the specific heat of various substances is given in the appendix, No. XV.

On Latent Heat.

(249.) We have now to proceed to our remaining class of results, viz. "*those in which the same substance is examined; but under changes in its physical condition.*"

atent heat. r. Black.

In this department we find some of the most striking and valuable properties arising out of that mysterious system of operations to which the great author of nature has subjected every form and atom of material substance. It will easily be conceived that we refer to the great discoveries of Dr. Black, which made known that form or property of caloric frequently termed LATENT HEAT. Of this, let us select the most familiar examples. In them we shall have a still further illustration that the thermometer is only a measure of apparent temperature; and that it can only indirectly give us any information as to the real quantity of caloric contained in the various kinds or states of matter. In short, it appears, that for body to undergo one of the great physical changes from one form of matter to another form, a very considerable change takes place in its specific caloric, though its sensible temperature may not be at all affected. To pass from the solid to the fluid, or from the fluid to the gaseous state, a very considerable quantity of heat is absorbed and rendered *latent*, or imperceptible to the thermometer; and in the converse operations of passing from the gaseous to the fluid, or from the fluid to the solid state, this heat is again liberated, and becomes sensible. Black's illustrations are as follows:

(250.) Let a mass of ice of the temperature 20° Fahrenheit be brought into a warm room: the temperature of the ice gradually rises to 32°; it then begins to melt, but during the process of melting, which occupies several hours, the temperature of the mass never rises above 32°. Doubtless the ice continues to receive caloric throughout the whole time as rapidly as at first, and therefore as no increase of sensible temperature above 32° is apparent, the heat added must have been employed in transforming the ice from the solid to the fluid state.

(251.) Two thin glass globes of nearly the same weight were suspended in a large room, at a distance from all other bodies. The one contained water at 33° Fahrenheit, the other a solid mass of ice. The temperature of the air in the room was 47° Fahrenheit. In half an hour the thermometer in the water rose to 40°; but it required 10½ hours to produce the entire liquefaction of the ice, and to raise the water in that glass to 40°. Supposing roughly that in the first half hour the water gained 7°, and that the ice globe continued through all the time of the experiment to receive heat at the same rate, it must in all have obtained 21 × 7 = 147° of heat, of which 7° only were sensible to the thermometer.

(252.) That in this, and such cases, the heat is rendered latent, but not destroyed, the following converse experiment proves. When the exposed thermometer is at 22°; let two vessels, the one filled with brine, the other with water, both at 52°, with a thermometer in each, be exposed till both are cooled down to 32°. The water freezes slowly, while its temperature remains 32°. The brine (not freezing but at a temperature 4° Fahrenheit) gradually cools down to 22°. From this it seems fair to infer, that both liquids are continually imparting caloric to the surrounding air; the one, as it undergoes no physical change, gives out caloric at the expense of its sensible temperature; the other is enabled to undergo a physical change by the loss of its caloric; and in making that change, one portion parts with a sufficient quantity of caloric superfluous to, or inconsistent with its new state, which goes to the remaining water from which it must be abstracted by the surrounding air, that a further portion of the liquid may be enabled to undergo the same process.

(253.) Again, Dr. Black mixed together 59½ drams of ice and 67½ drams of water. The effect of the glass vessel in which the experiment was made, he estimated as equal to that of 4 drams of water; so that the experiment may be considered as 59½ ice + 71½ hot water. The water was 190° Fahrenheit, the ice 32°. When the ice had melted the temperature of the water was 53°. The loss then upon the 71½ drams of water was 137°, and the gain to 59½ of ice 21°. But the heat of the mixture should be 118°, according to calculation for a mean, so that the rise of heat upon the ice should be 86°. Hence, it seems, that a quantity of heat which might have been expected to have produced an elevation of 65° more of temperature in the ice water, has totally disappeared or become latent.

From these data the absolute specific heat of water may also be determined.

Let m be the mass of water.
t its temperature.
c its specific caloric to be determined.
m' the mass of ice.
T the common temperature after mixture.

The caloric contained in this mixture above freezing point will $= (m + m') \, c \, \mathrm{T}$, because it has then all become liquid. To this we must add the caloric absorbed by the mass of ice m' in order to its fusion, which by the conditions of the experiment equal m'.

Hence $(m + m') \, c \, \mathrm{T} + m'$ = the total caloric of the mass of hot water at first above 32° *i e* $= m \, c \, t$.

Hence $$(m + m') \, c \, \mathrm{T} + m' = m \, c \, t$$

$$\therefore c = \frac{m'}{m t - (m + m') \, \mathrm{T}}$$

And substituting Black's numbers

$$m = 143 \, ; \; t = 190 - 32 = 158$$
$$m' = 119 \, ; \; \mathrm{T} = 53 - 32 = 21$$

$$c = \frac{119}{143 \times 158 - 262 \times 21} = \frac{119}{17132} = 0^\circ.0069 \text{ F.}$$

or on centigrade scale $= 0^\circ.0124$ C.

(254.) In another experiment Dr. Black added together equal weights of ice at 32° and water of 176° Fahrenheit. In this mixture the ice was just melted, and the temperature of the liquid did not rise above 32°. That is to say, ice in the process of liquefaction renders latent 144° of apparent heat in an equal weight of water.

But according to MM. Lavoisier and Laplace a volume of water at 167° Fahrenheit is sufficient for the fusion of an equal volume of ice at 32° Fahrenheit. The difference between these results is not very considerable. Black's experiment gives $\frac{1}{176} = .0056$ for the absolute specific heat of water; while that of the French experimentalists reduces the expression to $\frac{1}{167} = .005988$ on

Southern in 1803. He found it in three experiments made at very high temperatures, 942°, 942°, and 950°. (Rob. *Mech. Phil.* p. 165.) The experiments of Lavoisier make it rather more than 1000°. According to Rumford it amounts to 1040°.8. Dr. Ure, in a set of experiments lately published, states it at 967°. (*Phil. Trans.*, 1818, p. 388.) Thus we have the latent heats of steam as follows:

Watt	950°
Southern	945
Lavoisier	1000
Rumford	1040.8
Ure	967
Mean	980.5

Mr. Southern made a set of experiments to determine the latent heat of steam raised to a much higher temperature, and possessing much greater elasticity than common steam. The following table exhibits the results which he obtained:

Temperature of steam	Elasticity of steam in inches of mercury.	Latent heat.
229°	40	942°
270	80	942
295	120	950

From these results it seems to follow that the latent heat of steam is a constant quantity, whatever be its temperature and elasticity. An opinion, however, of Mr. Southern, which Mr. Watt informs us he has long entertained, deserves the attention of chemists, and the exercise of their ingenuity to contrive methods of putting it to the test of experiment. When air increases in bulk, its temperature at the same time diminishes. Hence if a portion of air were gradually expanded, and at the same time supplied with heat so as to keep the temperature unaltered, this additional dose of heat would not be indicated by the thermometer, or would be latent. There is every reason to believe that the same thing holds with steam. The latent heat of steam then is in reality twofold: 1st, the latent heat of elastic fluidity, or that which changes it from a liquid to an elastic fluid; 2nd, the latent heat of expansion, or the heat which becomes latent as the steam expands. It is the first of these only that can be considered as a constant quantity.

This view of the subject deserves the greater attention, because it enables us to explain a phenomenon, which at first view seems paradoxical. It is well known that if we expose any part of the body to steam of the temperature 212°, we receive a very severe burn; but we may plunge our hands into steam heated to 260° or higher, without any injury whatever. Steam of 212°, when issuing with violence from an orifice, is invisible for some space, or retains all the properties of an elastic fluid, and it is while in this state that it possesses the property of scalding. But high pressure steam becomes a cloud the instant it comes into the open air. I conceive the reason to be, that high pressure steam expands whenever it comes into the open air; the latent heat of expansion therefore is suddenly increased. Heat becomes latent at the expense of latent heat of elastic fluidity. A portion of the steam is therefore reduced to the state of particles of water. Hence the cloud which is formed. That portion which still remains in the state of vapour is then mixed with particles of water and of air. Consequently its particles are too far from each other to enable it to scald. Thus, suppose the temperature of the steam to be 350°, its elasticity will be twice that of air; whenever it goes into the atmosphere its bulk instantly doubles. A great deal of its sensible heat is absorbed by the increase of bulk, and the sensible heat being reduced, part of the steam is converted into water. Thus I conceive the temperature is rendered too low for scalding the human body.

By the experiments of Dr. Black and his friends, it was ascertained, that not only water, but all other liquids during their conversion into vapour, combine with a dose of caloric without any change of temperature; and that every kind of elastic fluid, during its conversion into a liquid, gives out a portion of heat without any change of temperature. The only persons who have tried to determine the latent heat of other elastic fluids, as far as my information goes, are Count Rumford and Dr. Ure. The former only determined the latent heat of alcohol, but Dr. Ure made experiments on a considerable number of fluids. The following table exhibits the results of these experiments:

Elastic fluids from	Latent heats.
Vinegar (sp. gr. 1.007)	875°
Liquid ammonia (sp. gr. 0.978)	837.28
Nitric acid (sp. gr. 1.494)	531.99
Alcohol (sp. gr. 0.825)	442
Alcohol	477 to 500
Sulphuric ether (boiling point 112°)	302.379
Petroleum	177.87
Oil of turpentine	177.87

The above determinations are all from Dr. Ure's paper *Phil. Trans.*, 1818, with the exception of alcohol, which is by Rumford, in Gilb. *An.*, xlv. p. 312.

Dr. Black's law, then, is very general, and comprehends every change in the state of the body. The cause of the conversion of a solid into a liquid is the combination of the solid with caloric; that of the conversion of a liquid into an elastic fluid is the combination of the liquid with caloric. Liquids are solids combined with caloric; elastic fluids are liquids combined with caloric. This law, in its most general form, may be stated as follows: *whenever a body changes its state, it either combines with caloric, or separates from caloric.*

No person will dispute that this is one of the most important discoveries hitherto made in chemistry. Science seems indebted for it entirely to the sagacity of Dr. Black. Other philosophers, indeed, have laid claim to it; but these claims are either without any foundation, or their notions may be traced to Dr. Black's lectures, or their opinions originated many years posterior to the public explanation of Dr. Black's theory in the chemical chairs of Glasgow and Edinburgh. (*aa.*)

Se also Despretz on the latent heat of vapours. (*dd.*)

(263.) Count Rumford's estimation of the latent heat of steam, affords another elegant application of his calorimeter. (157.) A given quantity of water was boiled in a long necked flask, which was bent so as to terminate under the mouth of the reflexed tube. The extremity of this flask was joined by a cork fitting accurately into the mouth of the calorimeter tube; the cork had four apertures opening horizontally within the tube, but so elevated above the bottom of the tube as not to be blocked up by the return of vapour condensed within the tube. The flask was heated by a small portable furnace at some distance from the calorimeter, which was also well defended by certain screens. The weight of the condensed vapour was deducted from that of the flask weighed before and after the operation, ples. By conveying steam into water, it is con-d, and by the evolution of the latent heat by the ation, the temperature of the water is raised, so as to arrive at 212°. In certain arts, as in that ing, where large quantities of water are to be in separate vessels, this method has superior tages. By having a common boiler, from which pour is conveyed by tubes, the loss of heat is if fire was applied to each vessel, and the are subject to less wear, and may be constructed expense. This method has accordingly been with success. Another application of the principle is that of heating rooms by conveying through tubes, proposed in an early volume of *phical Transactions*, and since revived. The in its progress is condensed gradually, and gives tent heat, so as to produce an equable warmth. nstructed apparatus for this purpose has been by Mr. Snodgrass, by whom it was applied to the heating of cotton mills. Mr. Bu-has, in a separate publication, given more details on this subject, which may be consulted ntage. For this and similar purposes steam adapted, as it has the advantage of being free danger of fire, the boiler whence the steam is being erected without the building; and there saving of fuel. There is a considerable ex-owever, in erecting the apparatus, on which and also as being more easily managed, the heating apartments by the introduction of may in particular situations be preferred. of applying heat from the condensation of been proposed to be applied to the drying iler, as attended with less risk than the mode.

dern improvements in the steam engine, as ned from Dr. Black's discovery, so they most important practical application of the latent heat. In the engine wrought previous provements of Mr. Watt, the steam was re-cylinder, to which a piston was adapted; the weight attached to its arm being top of the cylinder, and the cavity be-with steam. This was condensed by a jet and the piston was of course forced pressure of the atmosphere. To raise gain introduced from beneath, and elevation and depression of the piston But in this way, it is obvious, that there waste of heat, and this altogether the facts relating to latent caloric were jet of cold water, not only is the the cylinder is cooled, as it is also the atmospheric air. When, there-beneath is again introduced, a great part of it must be condensed and lost, by its heat being abstracted by the cold cylinder and piston, and its elasticity cannot operate with effect until the whole is again elevated to 212°. At each stroke of the engine this waste is repeated; and thus, according to Mr. Watt's calculation, at least half of the steam produced in the boiler is lost.

Mr. Watt's principal improvements consisted: first, in condensing the steam, not in the cylinder, but in a vessel communicating with it by a pipe with a valve, which being exhausted of air, the steam rushes into it when the communication is opened, and is condensed by the vessel being kept cold by immersion in water; and, secondly, by excluding from the cylinder the atmospheric air, and depressing the piston by steam introduced above it, and condensed in the condensing vessel alternately with the steam beneath. Thus the whole may be kept at the temperature of 212°, and the waste of heat in the old method obviated. Dr. Black justly characterises the engine in this state as the master-piece of human skill, and no less justly observes, that it has not been "the production of a chance observation, but the result of deep thought and reflection, and really a present by philosophy to the arts." (*bb*.)

References from (220) to (269) inclusive.

(*a*) Thenard, *Traité de Chem.*, i. p. 84. (*b*) Boerhaave, *Elementa Chimiæ*, i. p. 296. (*c*) Black's *Lect.*, i. 79, 504. (*d*) Irvine's *Chemical Essays*. (*e*) Wilcke, *Mém. Acad. Stock.*, 1781; or *Jour. de Phys.*, xxvi. (*f*) Lavoisier and Laplace, *Mém. Acad. Par.*, 1780; or *Mém. de Ch.*, tom. i. (*g*) Crawfurd, *on Animal Heat*, 1788. (*h*) Meyer, *An. de Ch.*, xxx. p. 46. (*i*) Lavoisier, *Mém. Acad. des Sciences*, 1777, p. 430. (*k*) Wedgwood, *Phil. Trans.*, lxxiv. p. 376. (*l*) Rumford's *Essays*. (*m*) Leslie, *Inquiry, &c.*, 1804, p. 340, 548. (*n*) Dalton, *Syst. Chem. Phil.* (*o*) Gay Lussac, *Mém. d'Arcueil*, i. p. 200; Ibid. *An. de Ch.*, lxxxi. p. 98; lxxxiii. p. 106. (*p*) Landriani, *Jour. de Phys.*, xxvi. p. 88. (*q*) Watt, *Phil. Trans.*, lxxiv. p. 335. (*r*) Irvine Jun. Nich. *Jour.*, ix. p. 45. (*s*) Delaroche and Berard, *An. de Ch.*, lxxxv. p. 72. (*t*) Dulong and Petit, *An. de Ch. et de Ph.*, vii. p. 113, 142. (*u*) Ibid., vol. x. p. 395. (*w*) Clement and Desormes, *Jour. de Phys.* (*x*) Ure, *An. Philos.*, Oct. 1817, vol. x. p. 273. (*y*) Ibid. *Phil. Trans.*, 1818, p. 378. (*z*) Poisson, *An. de Ch. et de Ph.*, xxiii. p. 337 and 407. Laplace, *Mech. Céleste*, lib. xii. (*aa*) Thomson's *Chemistry*, vol. i. p. 181. (*bb*) Murray's *Chemistry*, i. p. 420. (*cc*) Biot's *Phys.*, vol. iv. p. 718; also vol. i. ch. iii.; vol. iv. ch. v. (*dd*) Despretz, *An. de Ch. et de Ph.*, xxiv. p. 323. Fusinieri, *Giornale di Fisica di Pavia*, Feb. 1823, p. 34; and April, 1823, p. 131. Avogardo, *Mém. de l'Acad. des Sc. de Turin*, tom. xxviii. p. 1—122, and tom. xxix. p. 79—162.

1. Substances chemically dissimilar, have different capacities for heat, which may be investigated, and then represented in a tabular form.

2. With regard to the second class, we use the following quotation from M. Thenard.

"In mixing together, under ordinary atmospheric pressure, two portions of the same gas, equal in weight, unequal in temperature (20° to 25°,) and consequently in volume, we obtain a mixture of which the temperature is always more elevated than the mean of the two; whence it follows, that the capacity of a gas for heat increases with the temperature, dilatation being permitted." (Gay Lussac, *An. de Ch.*, lxxxi. p. 98.)

"It is probable, that if the volume varied but little, the augmentation of capacity would not become sensible but when the two portions of gas differed greatly in temperature. At least such is the observed fact in bodies of the same nature in the liquid state, and especially in the solid state, a property which they doubtless owe to their slight degree of dilatability.

"In fact the capacity of water for caloric is nearly the same from 10° C to 30°, as from 30° to 50°; also when we mix one kilogramme of water at + 10° with another of + 50° there results 2 kilogrammes at + 30°. The same is true of the capacities of mercury, zinc, &c. for similar intervals of temperature; while from 0° to 100° we find that the capacities are less than from 100° to 200°; and still less from 200° to 300°." (*a*)

3. And with regard to the third class, we have but to cite the law announced in Art. 266, that in every physical change of condition which any substance undergoes, there is either an evolution of caloric, which becomes sensible heat, or an absorption of caloric, which then becomes latent or insensible.

It is not in our power here to enter so fully into the theory of latent heat as we could desire, but a very short statement of the two opinions on this subject, which have excited the most attention, may be made as follows. Dr. Black considers the absorption of caloric in liquefaction and vapourisation, as the *cause* of those changes of form; and that, therefore, the latent heat existing in a liquid or vapour, is that which preserves it in these states. And he considered, says (Professor Robison) latent heat "as united with the substance of a body in a way very much resembling many chemical combinations." Irvine on the contrary supposed the phenomena of latent heat to arise from changes of capacity accompanying the changes of physical state. A very excellent comparative review of these opinions may be found in Murray's *Chemistry*, vol. i. p. 420, to 436.

Applica-
tions.

(269.) From this change in the distribution of caloric, which takes place when bodies change their forms, many chemical and natural phenomena are explained.

The absorption of heat, accompanying the change from the solid to the liquid form, explains the fixity of the point in the thermometrical scale at which bodies melt Ice melts at 32° of Fahrenheit, and whenever any mass of ice is heated to that temperature, the farther communication of heat, however rapid, has no effect in raising its temperature, till the whole is converted into water; since, as quickly as the ice is melted by the caloric, as quickly is a portion of it absorbed by the fluid formed. This is exemplified in the long time before large masses of ice, or collections of snow, are melted by a thaw. Were it not for this absorption of heat, the liquefaction of masses of ice and snow in the colder climates, at the approach of spring, would take place almost instantaneously, when the temperature of the atmosphere rose above 32°; whereas, from this circumstance, it is gradual and progressive, by which the water formed is distributed more slowly, and the too sudden rise of temperature, which would prove fatal to vegetables, is prevented.

The reverse of this, or the extrication of heat, when water is converted into ice, is equally beneficial; since, were it otherwise, the freezing of large collections of water would be extremely rapid, whenever the temperature of the atmosphere was at or below 32°. But from this extrication the freezing is gradual, and, at the same time, a large quantity of heat is given out by the water in passing to the solid state, by which the approaching cold is moderated, and the congelation rendered more slow.

Similar general effects arise from the operation of this law in vapourisation. When the earth is much heated by the sun's rays, water is evaporated from its surface and from rivers and the ocean, and the conversion o this into vapour is necessarily accompanied with th absorption into caloric. Hence evaporation is the most powerful agent employed by nature to moderate excessive heat. On the contrary, when the vapour of the atmosphere is condensed by cold, and descends in rain or snow, it gives out the caloric it had received, which is then beneficial rather than hurtful. Much of this vapour must even be wafted from the torrid zone, where evaporation must be most rapid, towards the polar regions; and being condensed in its progress in colder climates, will prove a source of heat.

The process of artificial refrigeration is explained on the same principle. By allowing water to filtrate slowly through porous earthen vessels, so as to present an extensive humid surface to the atmosphere, it passes rapidly into vapour, and in this vapourisation absorbs so much caloric as to produce considerable cold. Liquors are cooled, and in warm climates ice is formed, by arrangements of this kind, and this even when the temperature of the atmosphere is several degrees above 32°. This artificial formation of ice is carried on in Bengal to a considerable extent. The cold from the evaporation is no doubt considerably accelerated by the rapidity of that process from the dryness of the atmosphere, and hence, in a humid atmosphere, the process would not succeed at a similar average temperature. A considerable part o the effect too depends, as Dr. Wells has shown, o radiation from the surface of the water, and hence th success is always greatest in nights which are calm an serene.

The theory of freezing mixtures is deduced from t doctrine of latent caloric. These are mixtures of sali substances, which, at the common temperature, by th mutual chemical action, pass rapidly into the fl form, or are capable of being rapidly dissolved water, and by this quick transition to fluidity ab caloric, and produce degrees of cold more or intense.

In other cases of chemical action, substances from the gaseous to the fluid, or from the fluid t solid form, and the rise of temperature which a these transitions is referred to the evolution of caloric, which must be their result.

The use of steam, as a vehicle and source c affords an example of the scientific application

CHAPTER VI.

THEORETICAL OPINIONS ON THE NATURE OF HEAT.

Heat. (270.) In the five preceding chapters we have given as copious an abstract of those facts which experiment has developed concerning heat, as it is consistent with the plan of this work to allow. The very short chapter now before us will contain a statement of the two great systems of belief which philosophers have adopted with regard to the nature or cause of heat. As advocates for each of these theories, there will be found some of the most distinguished names that have ever done honour to the intellect of man; but, after all, their speculations have produced little that is convincing to others, or even satisfactory to themselves. For these reasons we have filled our pages chiefly with experiments, and hasten to conclude this already extended article.

Of these two principal theories the one admits the materiality of heat; while the other, denying that it is substance, considers it a property of matter producing its effects by an actual vibration among the molecules of that matter.

The vibratory hypothesis which is usually attributed to Bacon is thus explained in his own words, "*Calor est motus expansivus, cohibitus, et nitens per partes minores.*" Perhaps this is the same as if he had said that caloric is a force which is opposed to molecular attraction; and that heat is the effect of a vibration produced by these conflicting forces. Of this opinion also were Boyle and Newton; while Rumford and Sir Humphrey Davy have been its most recent and able advocates.

The material hypothesis, in which heat is considered a substance of extreme tenuity, of great elasticity, imponderable and invisible, is said to have been proposed by Boerhaave, and was advocated by Hamberg and Lemery. It seemed, in fact, much the most consistent with the notions of chemists; and can by no means be a matter of surprise that Black's discovery of latent heat should have been by them deemed a strong confirmation of this hypothesis.

Material hypothesis. (271.) In favour of the hypothesis that heat is material, it has been urged, that as its addition to bodies produces their expansion, it is most natural to suppose that this effect is owing to the actual insertion of a material substance between the molecules. But this, perhaps, is not quite conclusive; for if the magnitude of a body depend upon the arrangement of its molecules, and if these (as there is every reason to suppose) be endowed with polarity, then any change in the state of this polarity, producing a new arrangement of molecules, will produce a new magnitude of volume, providing the molecules be not spheres in strict contact.

The transfer of measured quantities of heat (to use a common phrase) to effect given purposes of expansion, fusion, vapourisation, or the contrary, has been urged with reason as a good argument on this side of the question. Those inclined to dispute, may say that it is only the application of a force accurately estimated, and of course producing from given quantities the same effects under given circumstances.

The passage of heat through a vacuum is also advanced, on the same side; because it is not possible to conceive how, if heat be a property of matter, it should be freely propagated where no matter exists. Let this also have its due weight; but let us remember that we are quite unable to produce an absolute vacuum, for that even in that which is called after Torricelli, there is an atmosphere of mercurial vapour, though of great tenuity.

If the experiments of Herschel and others have proved the distinct separation of heat from light in any case, and that the laws which they obey are analogous, though not identical; then the materiality of heat stands much upon the same evidence with that of light.

(272.) That heat is merely a property of matter, and that it may arise from vibrations of the molecules, has thus been urged:

Because the most careful experiments made for that purpose never could prove it to be ponderable. (*a.*) Thus it seems not to possess the ordinary sensible properties of matter, weight and obedience to the laws of mechanical motion.

On these grounds Count Rumford strongly urged the immateriality of heat, and also from the evidence of his own experiments, in which friction seemed an inexhaustible source of heat in the same given substance. With regard to the former proof arising from the absence of certain mechanical properties, it might be urged that these, being inappreciable by our experiments, is not a sufficient evidence of their non-existence.

The following sentences must serve to give an idea of the opinion of Sir Humphrey Davy on this most abstruse subject.

"The immediate cause of the phenomenon of heat, then, is motion; and the laws of its communication are precisely the same as the laws of the communication of motion. Since all matter may be made to fill a smaller volume by cooling, it is evident that the particles of matter must have space between them; and since every body can communicate the power of expansion to a body of a lower temperature; that is, can give an expansive motion to its particles, it is a probable inference that its own particles are possessed of motion; but as there is no change in the position of its parts, as long as its temperature is uniform, the motion, if it exist, must be a vibratory or undulatory motion, or a motion of the particles round their axes, or a motion of particles round each other"

APPENDIX.

TABLE (A) to Art. 63.

Linear Dilatation of Solids by Heat. (Ure.)

Dimensions which a bar takes at 212° whose length at 32° is 1.000000.

Glass tube	Smeaton	1.00083333
Ditto	Roy	1.00077615
Ditto	Deluc's mean	1.00082800
Ditto	Dulong and Petit	1.00086130
Ditto	Lavoisier and Laplace	1.00081166
Plate glass	Ditto	1.00089890
Ditto crown glass	Ditto	1.00087572
Ditto	Ditto	1.00089760
Ditto	Ditto	1.00091751
Ditto rod	Roy	1.00080787
Deal	Roy, as glass	
Platina	Borda	1.00085655
Ditto	Dulong and Petit	1.00088420
Ditto	Troughton	1.00099180
Ditto and glass	Berthoud	1.00110000
Palladium	Wollaston	1.00100000
Antimony	Smeaton	1.00108300
Cast iron prism	Roy	1.00110940
Cast iron	Lavoisier, by Dr. Young	1.00111111
Steel	Troughton	1.00118990
Ditto rod	Roy	1.00114470
Blistered steel	*Phil. Trans.* 1795, p. 428	1.00112500
Ditto	Smeaton	1.00115000
Steel not tempered	Lavoisier and Laplace	1.00107875
Ditto	Ditto	1.00107956
Ditto tempered yellow	Ditto	1.00136900
Ditto	Ditto	1.00138600
Ditto at a higher rate	Ditto	1.00123956
Steel	Troughton	1.00118980
Hard steel	Smeaton	1.00122500
Annealed steel	Muschenbroek	1.00122000
Tempered steel	Ditto	1.00137000
Iron	Borda	1.00115600
Ditto	Smeaton	1.00125800
Soft iron forged	Lavoisier and Laplace	1.00122045
Round iron, wire drawn	Ditto	1.00123504
Iron wire	Troughton	1.00144010
Iron	Dulong and Petit	1.00118203
Bismuth	Smeaton	1.00139200
Annealed gold	Muschenbroek	1.00146000
Gold	Ellicot, by comparison	1.00150000
Ditto procured by parting	Lavoisier and Laplace	1.00146606
Ditto, Paris standard, unannealed	Ditto	1.00155155
Ditto ditto annealed	Ditto	1.00151361
Copper	Muschenbroek	1.0019100
Ditto	Lavoisier and Laplace	1.00172244
Ditto	Ditto	1.00171222
Ditto	Troughton	1.00191880
Ditto	Dulong and Petit	1.00171821
Brass	Borda	1.00178300
Ditto	Lavoisier and Laplace	1.00186671
Ditto	Ditto	1.00188971
Brass scale, supposed from Hamburg	Roy	1.00185540
Cast brass	Smeaton	1.00187500
English plate brass, in form	Roy	1.00189280
Ditto, in a trough form	Ditto	1.00189190
Brass	Troughton	1.00191880
Ditto wire	Smeaton	1.00193000
Brass	Muschenbroek	1.00216000
Copper 8, tin 1	Smeaton	1.00181700
Silver	Herbert	1.00189000
Ditto	Ellicot, by comparison	1.0021000
Ditto	Muschenbroek	1.00212000
Ditto of cupel	Lavoisier and Laplace	1.00190974
Ditto, Paris standard	Ditto	1.00190868
Silver	Troughton	1.0020826
Brass 16, tin 1	Smeaton	1.00190800
Speculum metal	Ditto	1.00193300
Spelter solder; brass 2, zinc 1	Ditto	1.00205800
Malacca tin	Lavoisier and Laplace	1.00193765
Tin from Falmouth	Ditto	1.00217298
Fine pewter	Smeaton	1.00228300
Grain tin	Ditto	1.00248300
Tin	Muschenbroek	1.00284000
Soft solder; lead 2, tin 1	Smeaton	1.00250800
Zinc 8, tin 1, a little hammered	Ditto	1.00269200
Lead	Lavoisier and Laplace	1.00284836
Ditto	Smeaton	1.00286700
Zinc	Ditto	1.00294200
Ditto, hammered out half inch per foot	Ditto	1.00301100
Glass from 32° to 212°	Dulong and Petit	1.00086130
Ditto from 212° to 392°	Ditto	1.00091827
Ditto from 392° to 572°	Ditto	1.000101114

The last two measurements by an air thermometer.

TABLE (B) to Art. 80.

Elasticity of vapour below 32° by Dalton.	
Temperature.	Force in inches of mercury.
− 40	0.013
− 30	0.020
− 20	0.030
− 10	0.043
0	0.064
1	0.066
2	0.068
3	0.071
4	0.074
5	0.076
6	0.079
7	0.082
8	0.085
9	0.087
10	0.090
11	0.093
12	0.096
13	0.100
14	0.104
15	0.108
16	0.112
17	0.116
18	0.120
19	0.124
20	0.129
21	0.134
22	0.139
23	0.144
24	0.150
25	0.156
26	0.162
27	0.168
28	0.174
29	0.180
30	0.186
31	0.193

TABLE I. *To convert degrees, Fahrenheit.*

Fahr.	Reaum.	Cent.	Fahr.	Reaum.	Cent.	Fahr.	Reaum.	Cent.	Fahr.	Reaum.	Cent.
212	80.00	100.00	148	51.55	64 44	84	23.11	28.88	20	− 5.33	− 6.66
211	79.55	99.44	147	51.11	63.88	83	22.66	28.33	19	− 5.77	− 7.22
210	79.11	98.88	146	50.66	63.33	82	22.22	27.77	18	− 6.22	− 7.77
209	78.66	98.33	145	50.22	62.77	81	21.77	27.22	17	− 6 66	− 8.33
208	78.22	97.77	144	49.77	62.22	80	21.33	26.66	16	− 7.11	− 8.88
207	77.77	97.22	143	49.33	61 66	79	20.88	26.11	15	− 7.55	− 9.44
206	77.33	96.66	142	48.88	61.11	78	20.44	25.55	14	− 8.00	−10.00
205	76.88	96.11	141	48.44	60.55	77	20.00	25.00	13	− 8 44	−10.5
204	76.44	95.55	140	48.00	60.00	76	19.55	24.44	12	− 8.88	−11.11
203	76.00	95.00	139	47.55	59.44	75	19.11	23.88	11	− 9.33	−11.66
202	75.55	94.44	138	47.11	58.88	74	18.66	23.33	10	− 9.77	−12.22
201	75.11	93.88	137	46 66	58.33	73	18.22	22.77	9	−10.22	−12.77
200	74.66	93.33	136	46.22	57.77	72	17.77	22.22	8	−10.66	−13.33
199	74.22	92.77	135	45.77	57.22	71	17.33	21.66	7	−11.11	−13.88
198	73.77	92.22	134	45.33	56.66	70	16.88	21.11	6	−11.55	−14.44
197	73.33	91.66	133	44.88	56.11	69	16.44	20.55	5	−12.00	−15.00
196	72.88	91.11	132	44.55	55.55	68	16.00	20.00	4	−12.44	−15.55
195	72.44	90.55	131	44.00	55.00	67	15.55	19.44	3	−12.88	−16.11
194	72.00	90.00	130	43.55	54.44	66	15.11	18.88	2	−13.33	−16 6
193	71.55	89.44	129	43.11	53.88	65	14.66	18.33	1	−13.77	−17.22
192	71.11	88.88	128	42.66	53.33	64	14.22	17.77	0	−14.22	−17.77
191	70.66	88.33	127	42.22	52.77	63	13.77	17.22	−1	−14.66	−18.33
190	70.22	87.77	126	41.77	52.22	62	13.33	16.66	−2	−15.11	−18.88
189	69.77	87.22	125	41.33	51.66	61	12.88	16.11	−3	−15.55	−19.44
188	69.33	86.66	124	40.88	51.11	60	12.44	15.55	−4	−16.00	−20.00
187	68.88	86.11	123	40.44	50.55	59	12.00	15.00	−5	−16.44	−20.55
186	68.44	85.55	122	40.00	50.00	58	11.55	14.44	−6	−16.88	−21.11
185	68.00	85.00	121	39.55	49.44	57	11.11	13.88	−7	−17.33	−21.66
184	67.55	84.44	120	39.11	48.88	56	10.66	13.33	−8	−17.77	−22.22
183	67.11	83.88	119	38.66	48.33	55	10.22	12.77	−9	−18.22	−22.77
182	66.66	83.33	118	38.22	48.77	54	9.77	12.22	−10	−18.66	−23.33
181	66.22	82.77	117	37.77	47.22	53	9.33	11.66	−11	−19.11	−23.88
180	65.77	82.22	116	37.33	46.66	52	8.88	11.11	−12	−19.55	−24.44
179	65.33	81.66	115	36.88	46.11	51	8.44	10.55	−13	−20.00	−25.00
178	64.88	81.11	114	36.44	45.55	50	8.00	10.00	−14	−20.44	−25.55
177	64.44	80.55	113	36.00	45.00	49	7.55	9.44	−15	−20.88	−26.11
176	64.00	80.00	112	35.55	44.44	48	7.11	8.88	−16	−21.33	−26.66
175	63.55	79.44	111	35.11	43.88	47	6.66	8 33	−17	−21.77	−27.22
174	62.11	78.88	110	34.66	43.33	46	6.22	7.77	−18	−22.22	−27.77
173	62.66	78.33	109	34.22	42.77	45	5.77	7.22	−19	−22.66	−28.33
172	62.25	77.77	108	33.77	42.22	44	5.33	6.66	−20	−23.11	−28.88
171	61.77	77.22	107	33.33	41.66	43	4.88	6.11	−21	−23.55	−29.44
170	61.33	76.66	106	32.88	41.11	42	4.44	5.55	−22	−24.00	−30.00
169	60.88	76.11	105	32.44	40.55	41	4.00	5.00	−23	−24.44	−30.55
168	60.44	75.55	104	32.00	40.00	40	3.55	4.4	−24	−24.88	−31.11
167	60.00	75.00	103	31.55	39.44	39	3.11	3.88	−25	−25.33	−31.66
166	59.55	74.44	102	31.11	38.88	38	2.66	3.33	−26	−25.77	−32.22
165	59.11	73.88	101	30.66	38.33	37	2.22	2.77	−27	−26.22	−32.77
164	58.66	73.33	100	30.22	37.77	36	1.77	2.22	−28	−26.66	−33.33
163	58.22	72.22	99	29.77	37.22	35	1.33	1.66	−29	−27.11	−33.88
162	57.77	72.77	98	29.33	36.66	34	0.88	1.1	−30	−27.55	−34.44
161	57.33	71.66	97	28.88	36.11	33	0.44	0.55	−31	−28.00	−35.00
160	56.88	71.11	96	28.44	35.55	32	0.	0.	−32	−28.44	−35.55
159	56.44	70.55	95	28.00	35.00	31	−0.44	−0.55	−33	−28.80	−36.11
158	56.00	70.00	94	27.55	34.44	30	−0.88	−1.11	−34	−29.33	−36.66
157	55.55	69.44	93	27.11	33.88	29	−1.33	−1.66	−35	−29.77	−37.22
156	55.11	68.88	92	26.66	33.33	28	−1.77	−2.22	−36	−30.22	−37.77
155	54.66	68.33	91	26.22	32.77	27	−2.22	−2.77	−37	−30.66	−38.33
154	54.22	67.77	90	25.27	32.22	26	−2.66	−3.33	−38	−31.11	−38.88
153	53.77	67.22	89	25.33	31.66	25	−3.11	−3.88	−39	−31.55	−39.44
152	53.33	66.66	88	24.88	31.11	24	−3.55	−4.44	−40	−32.00	−40.00
151	52.88	66.11	87	24.44	30.55	23	−4.00	−5.00			
150	52.44	65.55	86	24.00	30.00	22	−4.44	−5.55			
149	52.00	65.00	85	23.55	29.44	21	−4.88	−6.11			

TABLE II. *To convert degrees, Centigrade.*

Cent.	Reaum.	Fahr.	Cent.	Reaum.	Fahr.	Cent.	Reaum.	Fahr.	Cent.	Reaum.	Fahr.
100	80.	212.	64	51.2	147.2	28	22.4	82.4	− 8	− 6.4	17.6
99	79.2	210.2	63	50.4	145.4	27	21.6	80.6	− 9	− 7.2	15.8
98	78.4	208.4	62	49 6	143.6	26	20.8	78.8	−10	− 8.	14.
97	77.6	206.6	61	48.8	141.8	25	20.	77.	−11	− 8.8	12.2
96	76.8	204.8	60	48.	140.	24	19.2	75.2	−12	− 9.6	10.4
95	76.	203.	59	47.2	138.2	23	18.4	73.4	−13	−10.4	8.6
94	75.2	201.2	58	46.4	136.4	22	17.6	71.6	−14	−11.2	6.8
93	74.4	199.4	57	45.6	134.6	21	16.8	69.8	−15	−12.	5.
92	73.6	197.6	56	44.8	132.8	20	16.	68.	−16	−12.8	3.2
91	72.8	195.8	55	44.	131.	19	15.2	66.2	−17	−13.6	1.4
90	72.	194.	54	43.2	129.2	18	14.4	64.4	−18	−14.4	− 0.4
89	71.2	192.2	53	42.4	127.4	17	13.6	62.6	−19	−15.2	− 2.2
88	70.4	190.4	52	41.6	125.6	16	12.8	60.8	−20	−16.	− 4.
87	69.6	188.6	51	40.8	123.8	15	12.	59.	−21	−16.8	− 5.8
86	68.8	186.8	50	40.	122.	14	11.2	57.2	−22	−17.6	− 7.6
85	68.	185.	49	39.2	120.2	13	10.4	55.4	−23	−18.4	− 9.4
84	67.2	183.2	48	38.4	118.4	12	9.6	53.6	−24	−19.2	−11.2
83	66.4	181.4	47	37.6	116.6	11	8.8	51.8	−25	−20.	−13.
82	65.6	179.6	46	36.8	114.8	10	8.	50.	−26	−20.8	−14.8
81	64.8	177.8	45	36.	113.	9	7.4	43.4	−27	−21.6	−16.6
80	64.	176.	44	35.2	111.2	8	6.2	46.2	−28	−22.4	−18.4
79	63.2	174.2	43	54.4	109.4	7	5.	44.6	−29	−23.	−20.2
78	62.4	172.4	42	33.6	107.6	6	4.8	42.8	−30	−24.2	−22.
77	61.6	170.6	41	32.8	105.8	5	4.	41.	−31	−24.2	−23.8
76	60.8	168.8	40	32.	104.	4	3.2	39.2	−32	−25.	−25.6
75	60.	167.	39	31.2	102.2	3	2.4	37.4	−33	−26.8	−27.4
74	59.2	165.2	38	30.4	100.4	2	1.6	35.6	−34	−27.	−29.2
73	58.4	163.4	37	29.6	98.6	1	0.8	33.8	−35	−28.	−31.
72	57.6	161.6	36	28.8	96.8	0	0.	32.	−36	−28.	−32.8
71	56.8	159.8	35	28.	95.	−1	−0.8	30.2	−37	−28.	−34.6
70	56.	158.	34	27.2	93.2	−2	−1.6	28.4	−38	−30.	−36.4
69	55.2	156.2	33	26.4	91.4	−3	−2.4	26.6	−39	−31.	−38.
68	54.4	154.4	32	25.6	89.6	−4	−3.2	24.8	−40	−32.	−40
67	53.6	152.6	31	24.8	87.8	−5	−4.	23.			
66	52.8	150.8	30	24.	86.	−6	−4.8	21.2			
65	52.	149.	29	23.2	84.2	−7	−5.6	19.4			

TABLE IV. *General Effects of Heat corresponding to certain Temperatures.* (Murray chiefly.)

		Fahrenheit.
Extremity of the scale of Wedgwood	240°	32277°
Greatest heat of an air furnace, 8 inches in diameter, which did not soften Nankeen porcelain	160	21877
Chinese porcelain softened, best sort	156	21357
Cast iron, thoroughly melted	150	20577
Hessian crucible melted	150	20577
Bristol porcelain not melted	135	18627
Cast iron begins to melt	130	17977
Greatest heat of a common smith's forge	125	17327
Plate glass furnace (strongest heat)	124	17197
Bow porcelain vitrifies	121	16807
Chinese porcelain softened, inferior sort	120	16677
Flint glass furnace (strongest heat)	114	15897
Derby porcelain vitrifies	112	15637
Stoneware baked in	102	14337
Welding heat of iron, greatest	95	13427
Welding heat of iron, least	90	12777
Cream-coloured ware baked in	86	12257
Flint glass furnace (weak heat)	70	10177
Working heat of plate glass	57	8487
Delft ware baked in	41	6407
Fine gold melts	32	5237
Settling heat of flint glass	29	4847
Fine silver melts	28	4717
Swedish copper melts	27	4587
Brass melts	21	3807
Heat by which enamel colours are burnt on	6	1857
Red heat fully visible in daylight	0	1077
Iron red hot in twilight	..	884
Heat of a common fire (Irvine)	..	790
Iron bright red in the dark	..	752
Zinc melts	..	700
Quicksilver boils (Irvine)	..	672
Quicksilver boils (Dalton)	..	660
Quicksilver boils (Crichton)	..	655
Linseed oil boils	..	600
Lead melts (Guyton, Irvine)	..	594
Sulphuric acid boils (Dalton)	..	590
The surface of polished steel acquires a deep blue colour	..	580
Oil of turpentine boils	..	560
Sulphur burns	..	—
Phosphorus boils	..	554
Bismuth melts (Irvine)	..	476
The surface of polished steel acquires a pale straw colour	..	460
Tin melts (Crichton, Irvine)	..	442
A compound of equal parts of tin and bismuth melts	..	283
Nitric acid boils	..	242
Sulphur melts	..	226
A saturated solution of salt boils	..	218
Water boils (the barometer being at 30 inches;) also a compound of 5 of bismuth, 3 of tin, and 2 of lead, melts	..	212
A compound of 3 of tin, 5 of lead, and 8 of bismuth, melts	..	210
Sodium fuses (Gay Lussac and Thenard)	..	194
Alcohol boils	..	174
Bees' wax melts	..	142
Potassium fuses (Gay Lussac and Thenard)	..	136
Spermaceti melts	..	133
Phosphorus melts (Thenard)	..	109
Phosphorus melts	.	100
Ether boils	..	98
Medium temperature of the globe	..	50
Ice melts	..	32
Milk freezes	..	30
Vinegar freezes at about	..	28
Strong wine freezes at about	..	20
A mixture of 1 part of alcohol and 3 parts of water freezes	..	7
A mixture of alcohol and water in equal quantities freezes	..	− 7
A mixture of 2 parts of alcohol and 1 of water freezes	..	− 11
Melting point of quicksilver (Cavendish)	..	− 39
Liquid ammonia crystallizes (Vauquelin)	..	− 42
Nitric acid, S. G. about 1.42, freezes, (Cavendish)	..	− 45
Sulphuric ether congeals (Vauquelin)	..	− 47
Natural temperature observed at Hudson's Bay	..	− 50
Ammoniacal gas condenses into a liquid (Guyton)	..	− 54
Nitrous acid freezes (Vauquelin)	..	− 56
Cold produced from diluted sulphuric acid and snow, the materials being at the temperature of − 57	..	− 78½
Greatest artificial cold yet measured (Walker)	..	− 91

Heat.

TABLE X. *Frigorific Mixtures without Ice.*

Mixtures.	Parts.	Thermometer sinks.	Degree of cold produced.
Muriate of ammonia	5	from + 50° to + 10°	40
Nitrate of potash	5		
Water	16		
Muriate of ammonia	5	from + 50 to + 4	46
Nitrate of potash	5		
Sulphate of soda	8		
Water	16		
Nitrate of ammonia	1	from + 50 to + 4	46
Water	1		
Nitrate of ammonia	1	from + 50 to − 7	57
Carbonate of soda	1		
Water	1		
Sulphate of soda	3	from + 50 to − 3	53
Diluted nitric acid	2		
Sulphate of soda	6	from + 50 to − 10	60
Muriate of ammonia	4		
Nitrate of potash	2		
Diluted nitric acid	4		
Sulphate of soda	6	from + 50 to − 14	64
Nitrate of ammonia	5		
Diluted nitric acid	4		
Phosphate of soda	9	from + 50 to − 12	62
Diluted nitric acid	4		
Phosphate of soda	9	from + 50 to − 21	71
Nitrate of ammonia	6		
Diluted nitric acid	4		
Sulphate of soda	8	from + 50 to 0	50
Muriatic acid	5		
Sulphate of soda	5	from + 50 to + 3	47
Diluted sulphuric acid	4		

N. B If the materials are mixed at a warmer temperature than that expressed in the table, the effect will be proportionably greater; thus, if the most powerful of these mixtures be made when the air is + 85°, it will sink the thermometer to + 2°.

TABLE XI. *Frigorific Mixtures with Ice.*

Mixtures.	Parts.	Thermometer sinks.	Degree of cold produced.
Snow, or pounded ice	2	from any temperature to − 5°	*
Muriate of soda	1		
Snow, or pounded ice	5	from any temperature to − 12	*
Muriate of soda	2		
Muriate of ammonia	1		
Snow, or pounded ice	24	from any temperature to − 18	*
Muriate of soda	10		
Muriate of ammonia	5		
Nitrate of potash	5		
Snow, or pounded ice	12	from any temperature to − 25	*
Muriate of soda	5		
Nitrate of ammonia	5		
Snow	3	from + 32 to − 23	55
Diluted sulphuric acid	2		
Snow	8	from + 32 to − 27	59
Muriatic acid	5		
Snow	7	from + 32 to − 30	62
Diluted nitric acid	4		
Snow	4	from + 32 to − 40	72
Muriate of lime	5		
Snow	2	from + 32 to − 50	82
Cryst. muriate of lime	3		
Snow	3	from + 32 to − 51	83
Potash	4		

The following Table, No. XV., presents a *comparative* view of the quantities of heat which different bodies contain at a given temperature; these are referred to water as a standard, calling its capacity 1.000. As the capacities of bodies are different, according as they exist in the solid, liquid, or aeriform state, the Table is divided according to those forms: the results obtained by different modes of experiment are placed in distinct classes. The Table from 1 to 151 contains the results obtained by the method of mixture and by the calorimeter; these agreeing in principle, the capacities found by them being inferred from measuring the quantity of caloric given out by a body in suffering a certain change of temperature, by the effect that quantity produces on another body to which it is communicated. Dr. Crawfurd's results form the basis of this Table, to which are added those established by Irvine, Wilcke, Gadolin, Lavoisier and Laplace, and Kirwan, and also the capacities of some solids ascertained by Mr. Dalton by this method. The Table from 152 to 175 comprises the capacities of bodies estimated from observing their times of cooling, established by the experiments of Leslie and Dalton. And the table from 175 to the end denotes the capacities of aerial fluids ascertained by Delaroche and Berard. The initial letter of the name of each author is annexed to the numbers; and where a difference exists in the capacity of any body, as ascertained by different Chemists, it is given according to each, with a reference by numbers within brackets, so that the authorities may be compared, and that selected on which it may be supposed most reliance is to be placed. (Murray.)

TABLE XV. *Capacities from Murray*, i. p. 252.

	Gases.		
1	Hydrogen gas (178)	21.4000	C.
2	Oxygen gas (180)	4.7490	—
3	Atmospheric air (177)	1.7900	—
4	Aqueous vapour (185)	1.5500	—
5	Carbonic acid gas (179)	1.0454	—
6	Nitrogen gas (181)	.7936	—
	Liquids.		
7	Solution of carbonate of ammonia (154)	1.8510	K.
8	Solution of brown sugar	1.0860	—
9	Alcohol, 15.44 (158)	1.0860	—
10	Arterial blood	1.0300	C.
11	Water	1.0000	—
12	Cow's milk (153)	.9999	—
13	Sulphuret of ammonia	.9940	K.
14	Solution of muriate of soda, 1 in 10 of water	.9360	G.
15	Alcohol (9, 44, 158)	.9300	Ir.
16	Sulphuric acid, diluted with 10 parts water	.9250	G.
17	Solution of muriate of soda in 6.4 of water	.9050	—
18	Venous blood	.8928	C.
19	Sulphuric acid, with 5 parts water	.8760	G.
20	Solution of muriate of soda in 5 of wate	.8680	—
21	Nitric acid (39, 159)	.8440	K.
22	Solution of sulphate of magnesia in 2 of water	.8440	—
23	Solution of muriate of soda in 8 of water	.8320	—
24	Solution of muriate of soda in 3.33 of water	.8208	G.
25	Solution of nitrate of potash in 8 of water	.8167	L.
26	Solution of muriate of soda in 2.8 of water	.8020	G.
27	Solution of muriate of ammonia in 1.5 of water	.7980	K.
28	Solution of muriate of soda saturated, or in 2.69 of water	.7930	G.
29	Solution of supertartrate of potash in 237.3 of water	.7650	K.
30	Solution of carbonate of potash	.7590	—
31	Colourless sulphuric acid (51, 55, 56, 57, 173)	.7580	—
32	Sulphuric acid with 2 parts of water	.7490	G.
33	Solution of sulphate of iron in 2.5 of water	.7340	K
34	Solution of sulphate of soda in 2.9 of water	.7280	—
35	Olive oil (172)	.7100	—
36	Water of ammonia, specific gravity 0.997, (152)	.7080	—
37	Muriatic acid, specific gravity 1.122 (169)	.6800	—
38	Sulphuric acid, 4 parts with 5 of water	.6631	L.
39	Nitric acid, specific gravity 1.29895 (21, 159)	.6613	—
40	Solution of alum in 4.45 of water	.6490	K.
41	Mixture of nitric acid with lime $9\frac{1}{3}$ tr. 1	.6189	L.
42	Sulphuric acid, with an equal weight of water	.6050	G.
43	Sulphuric acid, 4 parts with 3 of water	.6031	L.
44	Alcohol (9, 15, 158, 165)	.6021	C.
45	Nitrous acid, specific gravity 1.354	.5760	K.
46	Linseed oil	.5280	—
47	Spermaceti oil (53, 171)	.5000	C.
48	Sulphuric acid, with $\frac{1}{3}$ of water	.5000	G.
49	Oil of turpentine (52)	.4720	K.
50	Sulphuric acid with $\frac{1}{4}$ of water	.4420	G.
51	Sulphuric acid (31, 55, 5, 57, 173)	.4290	C.
52	Oil of turpentine (49)	.4000	Ir.
53	Spermaceti oil (47, 171)	.3990	K.
54	Red wine vinegar (155)	.3870	—
55	Sulphuric acid, concentrated and colourless (31)	.3390	G.
56	Sulphuric acid, specific gravity 1.87058	.3345	L.
57	Sulphuric acid (31, 51, 174)	.3330	Ir.
58	Spermaceti melted	.3200	—
59	Quicksilver, specific gravity 13.30 (175)	.0330	K.
60	Quicksilver	.0200	L.
61	Quicksilver	.0290	W.
62	Quicksilver	.0280	Ir.
	Solids.		
63	Ice	.9000	K.
64	Ice	.8000	Ir.
65	Ox hide with the hair	.7870	C.
66	Sheep's lungs	.7690	—
67	Beef of an ox	.7400	—
68	Rice	.5060	—
69	Horse beans	.5020	—
70	Dust of the pine-tree	.5000	—
71	Pease	.4920	—
72	Wheat	.4770	—
73	White wax	.4500	G.
74	Quicklime, with water, in the proportion of 16 to 9	.4391	L.
75	Barley	.4210	C.
76	Oats	.4160	—
77	Charcoal of brickwood (86)	.3950	G.
78	Carbonate of magnesia	.3790	—
79	Prussian blue	.3000	—
80	Quicklime	.3000	D.
81	Quicklime saturated with water, and dried	.2800	G.
82	Pit coal	.2800	D.
83	Pit coal	.2777	C.
84	Chalk	.2700	D.
85	Artificial gypsum	.2640	G.
86	Charcoal (77)	.2631	C.
87	Chalk (84, 96)	.2564	—
88	Rust of iron	.2500	—
89	White clay	.2410	G.
90	Sea salt (94)	.2300	D.
91	White oxide of antimony washed	.2272	C.
92	Oxide of copper	.2272	—
93	Quicklime (80, 95)	.2229	—
94	Muriate of soda in crystals (90)	.2260	G.
95	Quicklime (80, 93)	.2168	L.
96	Chalk (84, 87)	.2070	G.
97	Crown glass	.2000	Ir.
98	Agate, specific gravity 2648	.1950	W.
99	Earthenware	.1950	K.
100	Crystal glass without lead	.1929	L.
101	Cinders	.1923	C.
102	Flint glass, specific gravity 287 (106)	.1900	D.
103	Sulphur	.1900	—
104	Sulphur (109)	.1890	Ir. Jr.
105	Ashes of cinders	.1855	C.
106	White glass, specific gravity 2.386 (102)	.1870	W.
107	White clay burnt	.1850	G.
108	Black lead	.1830	—
109	Sulphur (103, 104)	.1830	K.

110	Oxide of antimony neai. free of air	.1666	C.
111	Rust of iron, nearly free of air	.1666	—
112	Ashes of elm wood	.1402	—
113	Iron (116, 118, 119, 123)	.1450	Ir.
114	Oxide of zinc, nearly freed from air	.1369	C.
115	White cast iron	.1320	G.
116	Iron	.1300	D.
117	White oxide of arsenic	.1260	G.
118	Iron (113, 116, 119, 123)	.1269	C.
119	Iron, specific gravity 7876,	.1260	W.
120	Cast iron abounding in plumbago	.1240	G.
121	Hardened steel	.1230	—
122	Steel softened by fire	.1200	—
123	Soft bar iron, specific gravity 7.724, (118)	.1190	G.
124	Brass, specific gravity 8.356, (126)	.1160	W.
125	Copper, specific gravity 8.785, (127)	.1140	—
126	Brass (124)	.1123	C.
127	Copper (125, 134)	.1111	—
128	Sheet iron	.1099	L.
129	Zinc, specific gravity 7154 (136)	.1020	W.
130	Zinc	.1000	D.
131	Nickel	.1000	D.
132	White oxide of tin, nearly free of air	.0990	C.
133	Cast pure copper, heated between charcoal, and cooled slowly, specific gravity 7907	.0990	G.
134	Hammered copper, specific gravity 9150	.0970	—
135	Oxide of tin (132)	.0960	K.
136	Zinc (129)	.0943	C.
137	Ashes of charcoal	.0909	—
138	Sublimed arsenic	.0840	G.
139	Silver, specific gravity 10.001	.0820	W.
140	Tin (145)	.0704	C.
141	Yellow oxide of lead	.0680	—
142	White lead	.0670	G.
143	Antimony	.0645	C.
144	Antimony, specific gravity 6.107	.0630	W.
145	Tin, specific gravity 7.380, (140)	.0600	—
146	Red oxide of lead	.0590	G.
147	Gold, specific gravity 1.904	.0500	W.
148	Vitrified oxide of lead	.0490	G.
149	Bismuth, specific gravity 9.861	.0430	W.
150	Lead, specific gravity .115	.0420	—
151	Lead	.0352	C.

Liquids.

152	Solution of ammonia, specific gravity 948, (36)	1.0300	D.
153	Milk, specific gravity 1.026, (12)	.9800	—
154	Solution of carbonate of ammonia, S. G. 1053, (7)	.9500	—
155	Common vinegar, specific gravity 1.02, (54)	.9200	D.
156	Solution of common salt, specific gravity 1.197	.7800	—
157	Solution of sugar, specific gravity 1.17	.7700	
158	Alcohol, specific gravity 85, (9, 15, 44)	.7600	—
159	Nitric acid, specific gravity 1.2, (21, 39)	.7600	—
160	Solution of carbonate of potash, specific gravity 130,	.7500	
161	Alcohol, specific gravity 817	.7000	—
162	Nitric acid, specific gravity 1.30, (39)	.6800	—
163	Acetic acid, specific gravity 1.056	.6600	—
164	Sulphuric ether, specific gravity 76	.6600	—
165	Alcohol (9, 15, 158, 161)	.6400	Les.
166	Nitric acid, specific gravity 136, (45)	.6300	D.
167	Nitric acid	.6200	Les.
168	Solution of nitrate of lime, specific gravity 1.4,	.6200	D.
169	Muriatic acid, specific gravity 1.153, (37)	.6000	—
170	Sulphuric acid and water, equal bulks,	.5200	—
171	Spermaceti oil (47, 53)	.5200	—
172	Olive oil (35)	.5000	Les.
173	Sulphuric acid, specific gravity 1.844	.3500	D.
174	Sulphuric acid (31, 51, 56)	.3400	Les.
175	Quicksilver (59, 60)	.0400	D.

Capacities of Gases for Caloric.

1. *Referred to Water as a Standard.*

176	Water	1.0000
177	Air (3)	0.2669
178	Hydrogen gas (1)	3.2936
179	Carbonic acid (5)	0.2210
180	Oxygen (2)	0.2361
181	Nitrogen (6)	0.2754
182	Nitrous oxide	0.2369
183	Olefiant gas	0.4207
184	Carbonic oxide	0.2884
185	Aqueous vapour (4)	0.8470

2. *Referred to Air as a Standard.*

		Specific heats of	
		Equal volume.	Equal weight.
186	Air	1.0000	1.0000
187	Hydrogen	0.9033	12.3401
188	Carbonic acid	1.2583	0.8280
189	Oxygen	0.9765	0.8848
190	Nitrogen	1.0000	1.0318
191	Nitrous oxide	1.3503	0.8878
192	Olefiant gas	1.5530	1.5763
193	Carbonic oxide	1.0340	1.0805

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The numbers refer to the bracketed numerals at the commencement of each paragraph.

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5. Opaque bodies intercept light. Many bodies possess the property of intercepting this peculiar intercourse between luminous bodies and our eyes, or other bodies. A screen of metal interposed between the sun and our eyes prevents our seeing it; interposed between the sun and a sheet of white paper, or other object, it *casts a shadow* on such object: *i.e.* renders it non-luminous. By this power of bodies to intercept light, we learn that the communication which constitutes it takes place in straight lines. We cannot see through a bent metallic tube, nor perceive the least glimpse of light through three small holes in as many plates of metal placed one behind the other at a distance, unless the holes be situated exactly in one straight line. Light emanates in straight lines, Moreover, the shadows of bodies, when fairly received on smooth surfaces perpendicular to the line in which the luminous body lies, are similar in figure to the section of the body which produces them, which could not be, except the light were communicated in straight lines from their edges to the borders of the shadow. We express this property by saying that light *emanates*, or *radiates*, or is *propagated* from luminous bodies in straight lines; by which expressions nothing more is to be understood than the mere fact, without in any way prejudging the question as to the intimate nature of this emanation. in all directions, Moreover, *it emanates from them in all directions*, for we see them in all situations of the eye, provided nothing intervene to intercept the light. This is the essential distinction between luminous bodies and optical images; from which, as we shall see, light emanates only in certain directions. Whether it emanates *equally* in all directions will be considered farther on.

6. and from every physical point in a luminous surface. Light also radiates from every point (at least from every *physical* point) of a luminous body. This may, perhaps, be regarded as a truism; for those points of a luminous body from which (as from the spots in the sun) no light emanates, are, in fact, non-luminous, and the body is only partially so; the figure of the spots is only seen, because it is also necessarily that of the luminous surface which surrounds them. Still it should be borne in mind, for reasons which will appear when we come to speak of the formation of images. It is possible (nay, probable) that a luminous surface, such as that of the flame of a candle, may consist only of an immense but finite number of luminous points, surrounded by non-luminous spaces; but it is not ocular demonstration this idea admits of; and it is sufficient for our purpose that, so far as our senses inform us, every physical point of a luminous surface is a *separate* and *independent* source of light. We may magnify in a telescope the sun's disc to any extent, and intercept all but the very smallest portions of it, (spots excepted,) yet the *visibility* of one part is no way impaired by the exclusion of the rest. In this sense the proposition is no truism, but an important fact, of which we shall hereafter trace the consequences.

7. When the sun shines through a small hole, and is received on a white screen behind at a considerable distance, we see a round luminous spot, which enlarges as the screen recedes from the hole. If we measure the diameter of this image at different distances from the hole, it will be found that (laying out of the question certain small causes of difference not now in contemplation) the angle subtended by the spot at the centre of the hole is constant, and equal to the apparent angular diameter of the sun. The reason of this is obvious; the light from every point in the sun's disc passes through the hole, and continues its course in a right line beyond it till it reaches the screen. Thus every point in the sun's disc has a point corresponding to it in the screen; and the whole circular spot on the screen is, in fact, an *image* or representation of the face of the sun. That this is really the case, is evidently seen by making the experiment in the time of a solar eclipse, when the image on the screen, instead of appearing round, appears horned, like the sun itself.* In like manner, if a pin-hole in a card be held between a candle and a piece of white paper in a dark room, an exact representation of the flame, but inverted, will be seen depicted on the paper, which enlarges as the paper recedes from the hole; and if in a dark room a white screen be extended at a few feet from a small round hole, an exact picture of all external objects, of their natural colours and forms, will be seen traced upon the screen; moving objects being represented in motion, and quiescent ones at rest. Fig. 6. (See fig. 6.) To understand this, we must recollect that all objects exposed to light are luminous; that from every physical point of them light radiates in all directions, so that every point in the screen is receiving light at once from every point in the object. The same may be said of the hole; but the light that falls on the hole passes through it, and continues its course in straight lines behind. Thus the hole becomes the vertex of a conoidal solid prolonged both ways, having the object for its base at one end, and the screen at the other. The section of this solid by the screen is the picture we see projected on it, which must manifestly be exactly similar to the object, and inverted, according to the simplest rules of Geometry.

8. Now if in our screen receiving (suppose) the image of the sun we make another small hole, and behind it place another screen, the light falling on the space occupied by this hole will pass beyond it, and reach the other screen; but it is clear that it will no longer dilate itself, after passing through the second hole, and form another image of the whole sun, but only an image of that very minute portion of the sun which corresponds to the space occupied in his image on the first screen by the hole made there. The lines bounding the conoidal surface will in this case have much less divergency, and, if the holes be small enough, and very distant from each other, will approach to physical lines, and that the nearer, as the holes are smaller and their distance greater. Fig. 7. (See fig. 7.) If we conceive the holes reduced to mere physical points, these lines form what we call rays of light. Mathematically speaking, a ray of light is an infinitesimal pyramid, having for its vertex a luminous point, and for its base an infinitely small portion of any surface illuminated by it, and supposed to be filled with the luminous emanation, whatever that may be. This pyramid, in homogeneous media, and when the course of the ray is not interrupted, has, as we have seen, ght. its sides straight lines. If cases should occur (as they will) when the course of the light is curved, or suddenly broken, we may still conceive such a pyramid having curved or broken sides to correspond; or we may (for brevity's sake) substitute for it a mere mathematical line, straight, curved, or broken, as the case may be.

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* In the eclipse of September 7, 1820, this horned appearance was very striking in the luminous interstices between the shadows of small irregular objects, as the leaves of trees, &c. It was noticed by those who had no idea of its cause.

9. ocity of t. Light requires time for its propagation. Two spectators at different distances from a luminous object suddenly disclosed, will not begin to see it at the same mathematical instant of time. The nearer will see it sooner than the more remote; in the same way as two persons at unequal distances from a gun hear the report at different moments. In like manner, if a luminous object be suddenly extinguished, a spectator will continue to see it for a certain time afterwards, as if it still continued luminous, and this time will be greater the farther he is from it. The interval in question is, however, so excessively small in such distances as occur on the earth's surface, as to be absolutely insensible; but in the immense expanse of the celestial regions the case is different. The eclipses and emersions of Jupiter's satellites become visible much sooner (nearly a quarter of an hour) when the earth is at its least distance from Jupiter than when at its greatest. *Light then takes time to travel over space.* It has a finite, though immense velocity, viz. 192500 miles per second; and this important conclusion, deduced by calculation from the phenomenon just mentioned, and which, if it stood unsupported, might startle us with its vastness, and incline us to look out for some other mode of explanation, receives full confirmation from another astronomical phenomenon, the *aberration* of light, which (without entering into any close examination of the mode in which vision is produced) may be explained as follows:

ation it. Let a ray of light from a star S, at such a distance that all rays from it may be regarded as parallel, be received on a small screen A, having an extremely minute opening A in its centre; and let that ray which passes through the opening be received at any distance A B, on a screen B perpendicular to its direction; and let B be the point on which it falls, the whole apparatus being supposed at rest. If then we join the points A, B by an imaginary line, that line will be the direction in which the ray has really travelled, and will indicate to us the direction of the star; and the angle between that line and any fixed direction (that of the plumb-line, for instance) will determine the star's place as referred to that fixed direction. For simplicity, we will suppose this angle nothing, or the star directly vertical; then the point B on which the ray falls will be precisely that marked by a plumb-line let fall from A; and the direction in which we judge the star to lie will coincide precisely with the direction of gravity. Such will be the case, supposing the earth, the spectator, and the whole apparatus at rest; but now suppose them carried along in a horizontal direction A C, B D, with a uniform and equal velocity, of whose existence they will therefore be perfectly insensible, and the pumb-line will hang steadily as before, and coincide with the same point of the screen. At the moment when the ray S A from the star passes through the orifice A, let A, B be the respective places of the orifice, and the point on the screen vertically below it. When the ray has passed the orifice, it will pursue its course in the same straight line S A B as before, independent of the motion of the apparatus, and in some certain time $\left(= \frac{\text{distance A B}}{\text{velocity of light}} = t\right)$ will reach the lower screen. But in this time the aperture, screens, and plumb-line will have moved away through a space

$$\mathrm{A}\,a = \mathrm{B}\,b \left(= t \times \text{velocity of motion} = \mathrm{A\,B} \times \frac{\text{earth's velocity}}{\text{velocity of light}}\right)$$

At the instant, then, that the ray impinges on the lower screen, the plumb-line will hang, not from A on B, but from a on b; and a being the *real orifice*, and B the *real point of incidence* of the light on the screen, the spectator, judging only from these facts, will necessarily be led to regard the ray as having deviated from its vertical direction, and as inclining from the vertical, in the direction of the earth's motion through an angle whose tangent is $\frac{\mathrm{A}\,a}{\mathrm{A\,B}}$ or $\frac{\text{earth's velocity}}{\text{velocity of light}}$.

1. The eye is such an apparatus. Its retina is the screen on which the light of the star or luminary falls, and we judge of its place only by the actual point on this screen where the impression is made. The pupil is the orifice. If, the eye preserving a fixed direction, the whole body be carried to one side with a velocity commensurate to that of light, before the rays can traverse the space which separates the pupil from the retina, the latter will have shifted its place; and the point which receives the impression is no longer the same which would have received it had the eye and spectator remained at rest; and this deviation is the *aberration of light.*

Every spectator on the earth participates in the general motion of the whole earth, which in its annual orbit about the sun is very rapid, and though far from equal to that of light, is by no means insensible, compared to it. Hence the stars, the sun, and planets, all appear removed from their true places in the direction in which the earth is moving.

2. This direction is varying every instant, as the earth describes an orbit round the sun. The direction therefore of the apparent displacement of any star from its true situation continually changes, *i. e.* the apparent place describes a small orbit about the true. This phenomenon is that alluded to. It was noticed as a fact by Bradley, while ignorant of its cause, that the stars appear to describe annually small ellipses in the heavens of about 40″ in diameter. The discovery of the velocity of light by the eclipses of Jupiter's satellites, then recently made by Roemer, however, soon furnished its explanation. Later observations, especially those of Brinkley and Struve, have enabled us to assign, with great precision, the numerical amount of this inequality, and thence to deduce the velocity of light, which by this method comes out 191515 miles per second, differing

from the former only by a two hundredth part of its whole quantity. This determination is certainly to be preferred.

14. Light uniform in its motion.

But this is not the only information respecting light which astronomical observations furnish. We learn from them also, "That the light of the sun, the planets, and all the fixed stars, travels with one and the same velocity." Now as we know these bodies to be at different and variable distances from us, we hence conclude that the velocity of light is independent of the particular source from which it emanates, and the distance over which it has travelled before reaching our eye.

15.

The velocity of light, therefore, in that free and perhaps void space which intervenes between us and the planets and fixed stars, cannot be supposed other than uniform; and the calculations of the eclipses of Jupiter's satellites, and the places of the distant planets made on this supposition agreeing with observation, prove it to be so. In entering such media as it traverses, when arrived within the limits of the atmospheres of the earth and other planets, we shall find reason hereafter to conclude that its velocity undergoes a change; but, at all events, we have no reason to suppose it to differ in different parts of one and the same homogeneous medium.

16. Velocity of light illustrated by comparisons.

The enormous velocity here assigned to light, surprising as it may seem, is among those conclusions which rest on the best evidence that science can afford, and may serve to prepare us for other yet more amazing numerical estimates. It is when we attempt to measure the vastness of the phenomena of nature with our feeble scale of units, such as we are conversant with on this our planet, that we become sensible of its insignificance in the system of the universe. Demonstrably true as are the results, they fail to give us distinct conceptions; we are lost in the immensity of our numbers, and must have recourse to other ways of rendering them sensible. A cannon ball would require seventeen years at least to reach the sun, supposing its velocity to continue uniform from the moment of its discharge. Yet light travels over the same space in 7½ minutes. The swiftest bird, at its utmost speed, would require nearly three weeks to make the tour of the earth. Light performs the same distance in much less time than is required for a single stroke of his wing; yet its rapidity is but commensurate to the distances it has to travel. It is demonstrable that light cannot possibly arrive at our system from the nearest of the fixed stars in less than five years, and telescopes disclose to us objects probably many thousand times more remote.

But these are considerations which belong rather to astronomy than to the present subject; and we will, therefore, return to the consideration of the phenomena of emitted light.

§ II. *Of Photometry.*

17. Light diminishes as the distance of its source increases.

Of these, one of the most striking is certainly the diminution of the illuminating power of any source of light, arising from an increase of its distance. We see very well to read by the light of a candle at a certain distance: remove the candle twice, or ten times as far, and we can see to read no longer.

The numerical estimation of the degrees of intensity of light constitutes that branch of optics which is termed *Photometry.* (*φως, μετρω.*)

18. Its intensity inversely as the square of the distance.

If light be a material emanation, a something scattered in minute particles in all directions, it is obvious that the same quantity which is diffused over the surface of a sphere concentric with the luminous points, if it continue its course, will successively be diffused over larger and larger concentric spherical surfaces; and that its intensity, or the number of rays which fall on a given space, in each will be inversely as the whole surfaces over which it is diffused; that is, inversely as the squares of their radii, or of their distances from the source of light. Without assuming this hypothesis, the same thing may be rendered evident as follows. Let a candle be placed behind an opaque screen full of small equal and similar holes; the light will shine through these, and be intercepted in all other parts, forming a pyramidal bundle of rays, having the candle in the common vertex. If a sheet of white paper be placed behind this, it will be seen dotted over with small luminous specks, disposed exactly as the holes in the screen. Suppose the holes so small, their number so great, and the eye so distant from the paper that it cannot distinguish the individual specks, it will still receive a general impression of brightness; the paper will appear illuminated, and present a mottled appearance, which, however, will grow more uniform as the holes are smaller, and closer, and the eye more distant; and if extremely so, the paper will appear uniformly bright. Now, if every alternate hole be stopped, the paper will manifestly receive only half the light, and will therefore be only half as much illuminated, and *cæteris paribus*, the degree of illumination is proportional to the number of the holes in the screen, or to the number of equally illuminated specks on its surface, *i. e.* if the specks be infinitely diminished in size, and infinitely increased in number, to the number of rays which fall on it from the original source of light.

19.

Let a screen, so pierced with innumerable equal and very small holes in the manner described, be placed at a given distance (1 yard) from a candle; and in the diverging pyramid of rays behind it place a small piece of white paper of a given area, (1 square inch, for instance,) so as to be entirely included in the pyramid. It is manifest that the number of rays which fall on it will be fewer as it is placed farther from the screen, because the whole number which pass the screen are scattered continually over a larger and larger space. Thus were it close to the screen it would receive a number equal to that of the holes in a square inch of the screen, but at twice the distance (2 yards) from the candle this number will be spread over four square inches by their divergence, and the paper can therefore receive only a fourth part of that number. If, therefore, its illumination when close to the screen be represented by 1, it will at twice the distance be only $\frac{1}{4}$, and at D times the assumed unit of distance, its illumination will be $\frac{I}{D^2}$, the areas of sections of a pyramid being as the squares of their distances from the vertex.

20. As this reasoning is independent of the number and size of the holes, and therefore of the ratio of the sum of their areas to that of the unperforated part of the screen, we may conceive this ratio increased *ad infinitum*. The screen then disappears, and the paper is freely illuminated. Hence we conclude that when a small plane object of given area is freely and perpendicularly exposed to a luminary at different distances, the quantity of light it receives, or the degree of its illumination, is inversely as the squares of its distance from the luminary, *cæteris paribus*.

21. mination portional the num- r and in- sity of rays;

If a single candle be placed before a system of holes in a screen, as before, and the rays received on a screen at a given distance, (1,) the degree of illumination may be represented by a given quantity, I. Now if a second candle be placed immediately behind the other, and close to it, so as to shine through the same holes, the illumination of the screen is perceived to be increased, though the number and size of the illuminated points on it be the same. Each point is then said to be more intensely illuminated. Now, (the eye being all along supposed so distant, and the illuminated points so small as to produce only a general sense of brightness, without distinguishing the individual points,) if the one candle be shifted a little sideways, without altering its distance, the illumination of the paper will not be altered. In this case the number of illuminated points is doubled, but each is illuminated with only half the light it had before. The same holds for any number of candles. Hence we conclude that the illumination of a surface is constant when the number of rays it receives is inversely as the intensity of each, and that consequently the degree of illumination is proportional to the number and intensity of the rays jointly.

Now if for any number of candles placed side by side we substitute mere physical luminous points, each of these will be the vertex of a pyramid of rays, and the number of equally illuminated points in the paper, and therefore illuminations will be proportional to the number of such points. If we conceive the number of these increased, and their size diminished *ad infinitum*, so as to form a continuous luminous surface, their number will be represented by its area. Hence the illumination of the paper will be, *cæteris paribus*, as the area of the illuminating surface, (supposed of uniform brightness.)

Uniting all these circumstances, we see that when a given object is enlightened by a luminous surface of small but sensible size, the degree of its illumination is proportional to the

$$\frac{\text{area of the luminous surface} \times \text{intensity of its illuminating power}}{\text{square of the distance of the surface illuminated}}.$$

The foregoing reasoning applies only to the case when the luminous disc is a small portion of a spherical surface concentric with the illuminated object, in which case all its points are equidistant from it, and all the light falls perpendicularly on the object. When the object is exposed obliquely, conceive its surface divided into equal infinitely small portions, and regard each of them as the base of an oblique pyramid, having its vertex at any one point of the luminary; then will the perpendicular section of this pyramid at the same distance be equal to the base × sine of inclination of the base to the axis, or the element of the illuminated surface × by the sine of the inclination of the ray. But the number of rays which falls on the base is evidently equal to those which fall on the section, and being spread over a larger area their effect will be to illuminate it less intensely in the proportion of the area of the section to that of the base, *i. e.* in the proportion of the sine of inclination to radius. But the illumination of the section is equal to the

$$\frac{\text{area of the luminary} \times \text{intrinsic brightness}}{(\text{distance})^2} \quad (23)$$

therefore that of the elementary surface equals this fraction multiplied by the sine of the rays' inclination; or, calling A the area of the luminary, I its intrinsic brightness, D its distance, and θ the inclination of the ray to the illuminated surface $\frac{A \,.\, I \sin \theta}{D^2}$ will represent the intensity of illumination

25. If L represent the absolute quantity of light emitted by the luminary *in a given direction*, which may be called its *absolute light*, we have $L = A \times I$, provided the surface of the luminary be perpendicular to the given direction. If not, A must represent the area of the section of a cylindroidal surface bounded by the outline of the luminary, and having its axis parallel to the given direction; consequently $\frac{L \,.\, \sin \theta}{D^2}$ represents in this case the intensity of illumination of the elementary surface.

To illustrate the application of these principles we will resolve the following

PROBLEM.

26. A small white surface is laid horizontally on a table, and illuminated by a candle placed at a given (horizontal) distance: What ought to be the height of the flame, so as to give the greatest possible illumination to the surface?

2. Let A be the surface, B C the candle. Put $AB = a \,.\, AC = D$; $BC = \sqrt{D^2 - a^2}$. Then, since the illumination of A is, *cæteris puribus*, as $\frac{\sin CAB}{AC^2}$, or as $\frac{CB}{AC^3} = \frac{\sqrt{D^2 - a^2}}{D^3}$ (= F) we have to make this

quantity a maximum; consequently $d\,\mathrm{F} = o$, or $d\,.\,\mathrm{F}^2 = o$, that is,

$$d\left\{\frac{1}{\mathrm{D}^4} - \frac{a^2}{\mathrm{D}^6}\right\} = o, \text{ or } -\frac{4}{\mathrm{D}^5} + \frac{6\,a^2}{\mathrm{D}^7} = o,\ 2\,\mathrm{D}^2 - 3\,a^2 = o,$$

$$\text{or } \mathrm{D} = a\,.\sqrt{\frac{3}{2}} \text{ and } \mathrm{B\,C} = \sqrt{\mathrm{D}^2 - a^2} = \frac{a}{\sqrt{2}} = 0.707 \times \mathrm{A\,B}.$$

27. Apparent magnitude defined. *Definition.* The *apparent superficial magnitude*, or the apparent magnitude of any object, is a portion of a spherical surface described about the eye as a centre, with a radius equal to 1, and bounded by an outline being the intersection of this spherical surface with a conoidal surface, having the object for its base and the eye for its vertex.

28. Hence the apparent superficial magnitude of a small object is directly as the area of a section (perpendicular to the line of sight) of this conoidal surface, at the place of the object, and inversely as the square of its distance. If the object be a surface perpendicular to the line of sight, this ratio reduces itself to the area of the object divided by the square of its distance.

29. Real intrinsic brightness defined. *Definition.* The *real intrinsic brightness* of a luminous object is the intensity of the light of each physical point in its surface, or the numerical measure of the degree in which such a point (of given magnitude) would illuminate a given object at a given distance, referred to some standard degree of illumination as a unit. When we speak simply of intrinsic brightness, *real intrinsic brightness* is meant.

30. *Corol.* 1. Consequently the degree of illumination of an object exposed perpendicularly to a luminary is as the apparent magnitude of the luminary and its intrinsic brightness jointly.

31. *Corol.* 2. Conversely, if these remain the same, the degree of illumination remains the same. For example, the illumination of direct sunshine is the same as would be produced by a circular portion of the surface of the sun of one inch in diameter, placed at about 10 feet from the illuminated object, and the rest of the sun annihilated; for such a circular portion would have the same apparent superficial magnitude as the sun itself This will serve to give some idea of the intense brightness of the sun's disc.

32. Apparent intrinsic brightness. *Definition.* The *apparent intrinsic brightness* of any object, or luminary, is the degree of illumination of its image or picture at the bottom of the eye. It is this illumination only by which we judge of brightness. A luminary may in reality be ever so much brighter than another; but if by any cause the illumination of its image in the eye be enfeebled, it will appear no brighter than in proportion to its diminished intensity. Thus we can gaze steadily at the sun through a dark glass, or the vapours of the horizon.

33. Absolute light defined. *Definition.* The *absolute light* of a luminary is the sum of the areas of its elementary portions, each multiplied by its own intrinsic brightness; or, if every part of the surface be equally bright, simply the area multiplied by the intrinsic brightness. It is, therefore, the same quantity as that above represented by L.

34. Apparent light defined. *Definition.* The *apparent light* of an object is the total quantity of light which enters our eyes from it, however distributed on the retina.

35. In common language, when we speak of the brightness of an object of considerable size, we often mean its *apparent intrinsic brightness*. When, however, the object has no sensible size, as a star, we always mean its *apparent light*, (or, as it might be termed, its *apparent absolute brightness*,) because, as we cannot distinguish such an object into parts, we can only be affected by its total light indiscriminately. The same holds good with all small objects which require attention to distinguish them into parts. Optical writers have occasionally fallen into much confusion for want of attending to these distinctions.

36. Diminution of apparent light by distance. As we recede from a luminary, its *apparent light* diminishes, from two causes; first, our eyes, being of a given size, present a given area to its light, and therefore receive from it a quantity of light inversely as the square of the distance; secondly, in passing through the air, a portion of the light is stopped, and lost from its want of perfect transparency. This, however, we will not now consider. In virtue of the first cause only, then, the apparent light of a luminary is inversely as the square of its distance, and directly as its *absolute light*.

37. Objects appear equally bright at all distances. The apparent intrinsic brightness is equal to the apparent light divided by the area of the picture on the retina of our eye. But this area is as the apparent superficial magnitude of the luminary, that is, as its real area A divided by the square of its distance D, or as $\frac{\mathrm{A}}{\mathrm{D}^2}$. Moreover, the apparent light, as we have just seen, is as $\frac{\mathrm{A\,I}}{\mathrm{D}^2}$ where I is the real intrinsic brightness. Consequently the apparent intrinsic brightness is proportional to $\frac{\mathrm{A\,I}}{\mathrm{D}^2} + \frac{\mathrm{A}}{\mathrm{D}^2}$, or simply to I, and is independent on A or D. The apparent intrinsic brightness is, therefore, the same at all distances, and is simply proportional to the real intrinsic brightness of the object. This conclusion is usually announced by optical writers by saying, that *objects appear equally bright at all distances*, which must be understood only of *apparent intrinsic brightness*, and the truth of which supposes also that no loss of light takes place in the media traversed. In what sense to be understood.

38. Angle of emanation defined. *The angle of emanation* of a ray of light from a luminous surface is the inclination of the ray to the surface at the point from which it emanates.

39. A question has been agitated among optical philosophers, whether the intensity of the light of luminous bodies be the same in all directions; or whether, on the other hand, it be not dependent on the angle of emanation. Euler, in his *Réflexions sur les divers degrés de la lumière du Soliel, &c.* Berlin, Mém. 1750, p. 280, has adopted

Illumination of a plane by any luminary investigated. Fig. 3.

plane B, fig. 3. Let P Q be any such portion, and let the pyramid B P be continued till it meets the surface of the heavens in p, there projecting the surface P Q into the areola $p\,q$, and let the whole luminary C D E F be in like manner projected into the disc $c\,d\,e\,f$. Let π Q be a section of the pyramid A P Q, perpendicular to its axis. Then, first, the plane B will be illuminated by the element P Q, just as it would be by a surface π Q equally bright, in virtue of the principle just established. Hence P Q is equivalent to an equally bright surface π Q. Again, since the apparent magnitude of π Q seen from B is the same with that of $p\,q$, the area π Q is equivalent to an equally bright area $p\,q$ placed at $p\,q$, (Art. 29, 30, 31, Cor. 1, 2.) P Q is, therefore, equivalent to $p\,q$. And since the same holds good of every other elementary portion of the surface, and the total light received by B is the sum of the lights it receives from all the elements of the luminary, the whole surface C D E F must be equivalent to its projection $c\,d\,e\,f$.

45. Hence the illumination of B depends, not at all on the real, but only on the apparent figure and magnitude of the luminary; and whatever the luminary be, we may always substitute for it a portion of the visible heavens, supposed of equal intrinsic brightness, and bounded by the same outline.

46. Thus, instead of the sun, we may suppose a small circle equal in apparent diameter to the sun, and equally bright; instead of a luminous rectangle perpendicular to the illuminated plane B, and of infinite height, as A G H I, fig. 3, we may substitute the spherical sector Z A G, bounded by the two vertical circles Z A, Z G, and so on.

47. Let then $p\,q$, any elementary rectangle infinitely small in both dimensions of the spherical surface, be represented by $d^2 A$, so that $\iint d^2 A$ shall represent the surface $c\,d\,e\,f$ itself; then if we put $z =$ the zenith distance Z p of this portion, its illuminating power on A will be $d^2 A \,.\, \cos z$, and the total illuminating power of the whole surface A will be

$$L = \iint d^2 A \,.\, \cos z.$$

General formula for illumination of a small plane.

48. *Example* 1. To find the illuminating power of the sector Z A G confined between any two vertical circles and the horizon. (fig. 3.) Here, putting θ for the azimuth of the element $d^2 A$, if we consider it as terminated by two contiguous verticals and two contiguous parallels of altitude, we have $d^2 A = d\,z \times d\,\theta \,.\, \sin z$. Hence we have

$$L = \iint d\,\theta\,d\,z \,.\, \sin z \,.\, \cos z = \tfrac{1}{2}\iint d\,\theta\,d\,z \,.\, \sin 2\,z = \tfrac{1}{2}\int (\theta + C)\,d\,z \,.\, \sin 2\,z\,;$$

and extending the integral from $\theta = o$ to $\theta =$ A G, the amplitude of the sector, (which we will call a,) we get

$$L = \frac{a}{2}\int d\,z.\ \sin 2\,z = \frac{a}{2}\,(C - \tfrac{1}{2}\cos 2\,z)$$

which extended from $Z = o$ to $z = 90°$ becomes simply $L = \frac{a}{2}$.

49. *Corol.* 1.. This is a measure of the illuminating power of the sector, on *the same scale* that that of an infinitely small area (A) placed at the zenith would be represented by A itself. Because in this case

$$\cos z = o, \text{ and } \iint d^2 A \,.\, \cos z = A.$$

50. *Corol.* 2. On the same scale the illuminating power of the whole hemisphere is π where $\pi = 3.14159535$

51. *Example* 2. Required the illuminating power of a circular portion of the heavens whose centre is the zenith. Calling z the zenith distance of any element, and θ its azimuth, we shall have, as before,

$$d^2 A = d\,\theta\,d\,z \,.\, \sin z, \text{ and therefore } L = \iint d\,\theta\,d\,z \,.\, \sin\ z \,.\, \cos\ z = \int \theta \,.\, \frac{d\,z \,.\, \sin 2\,z}{2} = \pi \int d\,z \,.\, \sin 2\,z$$

extending the integral from $\theta = o$ to $\theta = 2\,\pi$. That is $L = \pi \,.\, (\text{const} - \tfrac{1}{2}\cos 2\,z)$ which being made to vanish when $z = o$ becomes

$$L = \frac{\pi}{2}\,(1 - \cos 2\,z) = \pi \,.\, (\sin z)^2$$

52. *Corol.* 3. The illuminating power of a circular luminary, whose centre is in the zenith, is as the square of the sine of its apparent semidiameter.

53. *Example* 3. Required the illuminating power of any circular portion of the heavens whatever.

Illuminating power of any circular portion of an equally bright heaven.

Let T K L M be the illuminating circle; conceive it composed of annuli concentric with itself, and of one of them, X Y Z, (fig. 4,) let X x be an infinitesimal parallelogram terminated by contiguous radii S X and S x, S being the centre.

$$\text{Put } Z S = a;\ S X = x,\ Z X = z,$$

$$\text{Angle } Z S X = \phi,\ S T = r.$$

$$\text{Area } d^2 A = X x, = d\,x \times d\,\phi \,.\, \sin x$$

$$\therefore L = \iint d\,\phi\,d\,x \,.\, \sin x \,.\, \cos z.$$

but, by spherical trigonometry, $\cos z = \cos a \,.\, \cos x \,. + \sin a \,.\, \sin x \cos \phi$.

60. However, the eye, under favourable circumstances, is a tolerably exact judge of the *equality* of two degrees of illumination seen at once; and availing ourselves of this, we may by proper management obtain correct information as to the relative intensities of all lights. What these favourable circumstances are, we come now to consider.

The eye capable of judging of the equality of two degrees of illumination, and under what circumstances.

1st. The degrees of illumination compared must be of moderate intensity. If so bright as to dazzle, or so faint as to strain the eye, no correct judgment can be formed.

Hence, it is rarely adviseable to compare two luminaries directly with each other. It is generally better to let them shine on a smooth white surface, and judge of the degree in which they illuminate it; for it is an obvious axiom, *That two luminaries are equal in absolute light when, being placed at equal distances from, and in similar situations with respect to, a given smooth white surface, or two equal and precisely similar white surfaces, they illuminate it or them equally.*

Axiom in photometry.

63. 2nd. The luminaries, or illuminated surfaces compared, must be of equal apparent magnitude, and similar figure, and of such small dimensions as to allow of the illumination in every part of each being regarded as the same.

64. 3rd. They must be brought close together, in apparent contact; the boundary of one cutting upon that of the other by a well-defined straight line.

65. 4th. They should be viewed at once by the same eye, and not one by one eye, and the other by the other.

66. 5th. All other light but that of the two objects whose illumination is compared should be most carefully excluded.

67. 6th. The lights which illuminate both surfaces must be of the same colour. Between very differently coloured illuminations no exact equalization can ever be obtained, and in proportion as they differ our judgment is uncertain.

68. When all these conditions obtain, we can pronounce very certainly on the equality or inequality of two illuminations. When the limit between them cannot be perceived, on passing the eye backwards and forwards across it, we may be sure that their lights are equal.

69. Bouguer's principle of comparative photometry.

Bouguer, in his *Traité d'Optique*, 1760, p. 35, has applied these principles to the measure or rather the comparison of different degrees of illumination. Two surfaces of white paper, of exactly equal size and reflective power, (cut from the same piece in contact,) are illuminated, the one by the light whose illuminating power is to be measured, the other by a light whose intensity can be varied at pleasure by an increase of distance, and can therefore be exactly estimated. The variable light is to be removed, or approached, till the two surfaces are judged to be equally bright, when, the distances of the luminaries being measured, or otherwise allowed for, the measure required is ascertained.

70. Ritchie's photometer:

Mr. Ritchie has lately made a very elegant and simple application of this principle. His photometer consists of a rectangular box, about an inch and a half or two inches square, open at both ends, of which A B C D (fig. 5) is a section. It is blackened within, to absorb extraneous light. Within, inclined at angles of 45° to its axis, are placed two rectangular pieces of plane looking-glass F C, F D, *cut from one and the same rectangular strip*, of twice the length of either, to ensure the exact equality of their reflecting powers, and fastened so as to meet at F, in the middle of a narrow slit E F G about an inch long, and an eighth of an inch broad, which is covered with a slip of fine tissue or oiled paper. The rectangular slit should have a slip of blackened card at F, to prevent the lights reflected from the looking-glasses mingling with each other.

71. its use.

Suppose we would compare the illuminating powers of two sources of light (two flames, for instance) P and Q. They must be placed at such a distance from each other, and from the instrument between them, that the light from every part of each shall fall on the reflector next it, and be reflected to the corresponding portion of the paper E F or F G. The instrument is then to be moved nearer to the one or the other, till the paper on either side of the division F appears equally illuminated. To judge of this, it should be viewed through a prismoidal box blackened within, one end resting on the upper part A B of the photometer; the other applied quite close to the eye. When the lights are thus exactly equalized, it is clear that the total illuminating powers of the luminaries are directly as the squares of their distances from the middle of the instrument.

72. Experimental proof of the diminution of light as the squares of the distances.

By means of this instrument we are furnished with an easy experimental proof of the decrease of light as the inverse squares of the distances. For if we place four candles at P, and one at Q, (as nearly equal as possible, and burning with equal flames,) it is found that the portions E F, G F of the paper will be equally illuminated when the distances P F, Q F are as 2 : 1, and so for any number of candles at each side.

73. To render the comparison of the lights more exact, the equalization of the lights should be performed several times, turning the instrument end for end each time. The mean of the several determinations will then be very near the truth.

74. Another construction.

In some cases the looking-glasses are better dispensed with, and a slip of paper pasted over them, so as to present two oblique surfaces of white paper inclined at equal angles to the incident light. In this case the paper stretched over the slit E F G is taken away, and the white surfaces below examined and compared. One advantage of this disposition is the avoiding of a black interval between the two halves of the slit, which renders the exact comparison of their illuminations somewhat precarious.

75. Comparison of lights of different colours.

If the lights compared be of different colours (as daylight, or moonlight, and candlelight,) their precise equalization is impracticable, (art. 67.) The best way of employing the instrument, in this case, is to move it till one of the sides of the slit (in spite of the difference of colours) is judged to be decidedly the brighter, and then to move it the other way, till the other becomes decidedly the brighter. The position half way between these points is to be taken as the true point of equal illumination.

76. If we would compare the degrees of illumination, or the intrinsic brightnesses of two surfaces, a given portion of each must be insulated for examination; this may be best done by the adaptation of two blackened tubes to

the openings of the photometer, of equal length, and terminated by orifices of equal area, or subtending equal angles at the middle of the instrument. These, of course, cut off equal apparent magnitudes of the bright surfaces, the light of which is then to be equalized on the oiled papers of the slit E F, as in the case of candles, &c. Bouguer, *Traité*, p. 31.

Part I.

Another method of comparing the intensity of the light from two luminaries, which is also very ready and convenient, and possesses in some cases considerable advantages, has been proposed by Count Rumford. (See *Phil. Trans.*, vol. 84, p. 67.) It consists in the equalization of the *shadows* cast by them on a white surface illuminated by them both at once. Suppose, for instance, we would compare the illuminating power of two flames L and *l* of different sizes, or from different combustibles, as of wax and tallow. Before a screen C D of white paper, in a darkened room, place a blackened cylindrical stick S, and let the flames L *l* be so placed as to throw the shadows A B of the stick on the screen, side by side, and with an interval between them about equal in breadth to either shadow. Moreover the inclination of the rays L S A and *l* S B to the surface of the screen must be adjusted to exact equality. The brighter flame must then be removed, or the feebler brought nearer to the screen, till the two shadows appear of equal intensity, when their distances (or the distance of the screen) from the lights must be measured, and their total illuminating powers will be in the direct ratio of the squares of the distances. The rationale of this is obvious, the shadow thrown by each flame is illuminated by the light of the other. The screen by the sum of the lights. The eye in this case judges of the degrees of defalcation of brightness from this sum; and if these degrees be alike, it is clear that the remaining illuminations must be equal.

This method becomes uncertain when the lights are of considerable size and near the screen, as the penumbræ of the shadows prevent any fair comparison of the relative intensities of their central portions. It is still more so, and can hardly be used when the lights differ considerably in colour. Its convenience, however, as an extemporaneous method, requiring no apparatus but what is always at hand, (as the use of a *blackened* stick, though preferable, is not essential,) renders it often useful in the absence of more refined means.

It may happen that the lights to be compared are not movable, or not conveniently so. In this case the equalization of the shadows may be performed by inclining the screen at different angles to the directions in which it receives the light of each, and noting the angles of inclination of the rays. In this case the illuminating powers of the luminaries are as the squares of their distances directly, and the sines of the respective angles of inclination of their rays to the screen inversely.

When a ray of light proceeds in empty space, or in a perfectly homogeneous medium, its course, as we have seen, is rectilinear, and its velocity uniform; but when it encounters an obstacle, or a different medium, it undergoes changes or modifications which may be stated as follows:

It is separated into several parts, which pursue different courses, or are otherwise differently modified. One of these parts is *regularly reflected*, and pursues, after reflexion, a course wholly exterior to the new medium, or obstacle.

A second and a third portion are *regularly refracted*, that is, they enter the medium, and there pursue their course according to the *laws of refraction*. In many media these portions follow the same course precisely, and *perhaps* are no way distinguishable from each other. In such media (comprehending most uncrystallized substances and liquids) the refraction is said to be *single*. In numerous others (for instance in most crystallized media) they follow different courses, and also retain different physical characters. In these the refraction is said to be *double*.

A fourth portion is scattered in all directions, one part being intromitted into the medium, and distributed over the hemisphere interior to it, while the other is in like manner scattered over the exterior hemisphere. These two portions are those which render visible the surfaces of bodies to eyes situated any how with respect to them, and are therefore of the utmost importance to vision.

Of those portions which enter the medium, a part more or less considerable is *absorbed*, stifled, or lost, without any further change of direction; and that not at once, but progressively, as they penetrate deeper and deeper into its substance. In perfectly opaque media, such as the metals, this *absorption* is total, and takes place within a space less than we can appreciate; yet even here we have good reasons for believing that it does not take place *per saltum*. In crystallized bodies, those at least which are coloured, this absorption takes place differently on the two portions into which the regularly refracted ray is divided, according to laws to be explained when we come to treat of the absorption of light.

The regularly refracted portions of a ray of white or solar light are (except in peculiar circumstances) separated into a multitude of rays of different colours, and otherwise differing in their physical properties, each of which rays pursues its course afterwards, independently of all the rest, according to the laws of regular refraction or reflexion. The laws of this separation, or *dispersion*, of the coloured rays, and their physical and sensible properties, form the subject of *Chromatics*.

All those portions which are either regularly reflected, or regularly refracted, undergo, more or less, a modification termed *polarization*, in virtue of which they present, on their encountering another medium, different phenomena of reflexion and refraction from those presented by *unpolarized* light. Generally speaking, *polarized* light obeys the same laws of reflexion and refraction as *unpolarized*, as to the *directions* which the several portions, into which it is divided on encountering a new medium, take; but differs from it in the relative intensities of those portions, which vary according to the situation in which the surface of the medium and certain imaginary lines, or axes within it, are presented to the polarized ray.

The rays of light under certain circumstances exercise a mutual influence on each other, increasing, diminishing, or modifying each other's effects according to peculiar laws. This mutual influence is called the *interference* of the rays of light. We shall proceed to treat of these several modifications in order; and first of the regular reflexion of light.

§ 3. *Of the regular Reflexion of unpolarized Light from Plane Surfaces.*

88. When a ray of light is incident on a smooth-polished surface, a portion of it is regularly reflected, an pursues its course after reflexion in a right line wholly exterior to the reflecting medium. The directio and intensity of this portion are the objects of inquiry in this section; the physical properties acquired b the ray in the act of reflexion being reserved for examination at a more advanced period. And first, wi regard to the direction of the reflected ray. This is determined by the following laws:

Laws of Reflexion.

89. Laws of reflexion. *Law* 1. When the reflecting surface is a plane. At the point on which the ray is incident raise a perpendicul The reflected ray will lie in the same plane with this perpendicular, and with the incident ray. It will on the opposite side of the perpendicular, and will make an angle with it equal to that made by the i cident ray.

90. The plane in which the perpendicular to any surface at the point of incidence, and the incident ray, bo lie, is called the *plane of incidence.*

91. The angle included between the incident ray and the perpendicular is called the *angle of incidence.*

92. The plane in which the reflected ray and perpendicular both lie is called the *plane of reflexion;* and t angle included between the perpendicular and reflected ray is, in like manner, termed the *angle of r flexion.*

93. Adopting these definitions, the law of reflexion from a plane surface may be announced by saying, th the plane of reflexion is the same with that of incidence, and the angle of reflexion equal to that of incidence but situated on the contrary side of the perpendicular.

94. *Corol.* The incident and reflected rays are equally inclined to the surface at the point of incidence.

Law 2. When the surface is a curved one, the course of a ray reflected from any point is the same as i it were reflected at the same point from a plane, a tangent to the curve surface at that point; *i. e.* if perpendicular be raised to the curve surface at the point of incidence, the reflected ray will lie in the plan of incidence, and the angle of reflexion will equal that of incidence.

95. Demonstrated by experiment. The demonstration of these laws is a matter of experiment. If we admit a small sunbeam through hole in the shutter of a darkened chamber, and receive it on a polished surface of glass, or metal, we ma easily with proper instruments measure the inclinations of the incident and reflected rays to the surface which will be found equal. But this method is rude and coarse. A much more delicate verification of th law is afforded by astronomical observations. It is the practice of astronomers to observe the altitudes the stars above the horizon by direct vision; and, at the same instant, the apparent depression below t horizon of their images reflected at the surface of Mercury, (which is necessarily exactly horizontal,) and th depression so observed is always found precisely equal to the altitude, whatever the latter may be, whether gre or small. Now as these observations, when made with large instruments, are susceptible of almost math matical accuracy, we may regard the law of reflexion, on plane surfaces, as the best established in nature.

96. Reflexion at a curved surface may be considered as taking place at that infinitely small portion of surface which is common to it, and to its tangent plane at the point of incidence; so that if a perpendicu to the surface be erected at the point of incidence, the incident and reflected rays will make equal angles wit on opposite sides.

97. *Proposition.* To find the direction of a ray of light after reflexion at any number of plane surfaces, give position.

Construction. Since the *direction* of the ray after reflexion is the same whether it be reflected at the gi surfaces, or at surfaces parallel to them, conceive surfaces parallel to the given ones to pass through point C, (fig. 9,) and from C draw the straight lines CP, CP', CP'', &c. respectively perpendicular to t respective surfaces, and lying wholly exterior to the reflecting media. Draw SC parallel to the ray w incident on the first surface, and in the plane SCP, and on the opposite side of CP, from the incident ray make the angle $PCs' = PCS$, then will Cs' be the direction of the ray after reflexion at the first sur Prolong $s'C$ to S', then $S'C$ will represent the ray at the moment of its incidence on the second surface, w normal is CP'. Again, make the angle $P'Cs''$ in the plane $S'CP''$, but on the other side of CP', equal the angle $S'CP'$, then will Cs'' represent the ray at the moment of its reflexion from the second surface, a producing $s''C$ to S'', $S''C$ will represent it at the moment of its incidence on the third surface, whose nor is CP''. Similarly in the plane $S''CP''$; but on the other side of CP'' make the angle $P''Cs''' = P''CS$ and Cs''' will be the direction of the ray at the moment of its quitting the third surface, and so on. Fig 9.

98. Fig. 10. *Analysis.* About C as a centre conceive a spherical surface described, (fig. 10,) then will the pla PSs intersect it in a great circle $PSS'p$, and the plane in which CP, CP' lie, or the plane at right angle to the two first reflecting planes in another great circle $PP'p$, and the planes $S'Cs''$ and SCs'' in other great circles $S'P's''$ and Sks''.

Since CP and CP' are given directions, the angle PCP', or the arc PP' (which is equal to *the inclination of the two first surfaces to each other*) is given. Call this I. Again, since the direction SC of the incident ray is given, *the angle of incidence,* or the *first surface* PCS $(= a)$ and the angle SPP', or *the inclination of the plane of the first reflection to the plane* PP' *perpendicular to both surfaces* $(= \psi)$ are given. Hence in the spherical triangle P P′ S′ we have $PP' = I$; $PS' = 180° - \alpha$; and the angle $P'PS' = \psi$; consequently S′ P′, and therefore $2S'P' = S's''$ and the angle S S′ P′ are known, as also the angle P P′ S′, and therefore its supplement P P′ s″, which is the angle made by the second reflexion with the plane P P′. Again, in the spherical triangle S S′ s″ we have given $SS' = 180° - 2\alpha$; $S's'' = 2S'P'$ and the included angle S S′ s″, whence the third side S s″ may be found, which is the angle between the incident and twice reflected rays.

Similarly, if a third reflexion be supposed, we have given $P'S'' = 180° - S'P'$; $P'P'' = I'$, and the angle $S''P'P'' = S'P'P'' = PP'P'' - PP'S'$, whence we may compute S″ P″ and proceed as before, and so on to any extent.

Confining ourselves however to the case of two reflexions we have, by spherical trigonometry, putting $P'S' = \alpha' =$ *the angle of incidence on the second reflecting surface*, $PS'P' = \theta$; $PP'S' = \phi$, and $180° - Ss'' = D$, *the deviation of the ray after the second reflexion*, the following equations: 99.

General equations of reflexion at two planes.

$$\left.\begin{aligned} -\cos\alpha' &= \cos\alpha \,.\, \cos I - \sin\alpha \,.\, \sin I \,.\, \cos\psi \\ \sin\theta &= \frac{\sin I}{\sin\alpha'} \,.\, \sin\psi \\ \sin\phi &= \frac{\sin\alpha}{\sin\alpha'} \,.\, \sin\psi \\ \cos D &= \cos 2\alpha \,.\, \cos 2\alpha' - \sin 2\alpha \,.\, \sin 2\alpha' \,.\, \cos\theta \end{aligned}\right\} \quad (A)$$

100. Values of the symbols.

From these equations, any three of the seven quantities α, α', I, θ, ϕ, ψ, D being given, the other four may be found. It will be observed, that ϕ is *the angle between the plane of the second reflexion and the principal section of the two reflecting planes, and θ the angle between the planes of the first and second reflexion.* If ϕ and D only be sought, θ must be regarded as merely an auxiliary angle; but this may not be the case, and cases may occur in which θ alone may be sought, or in which it enters as a given quantity, &c. In short, the foregoing equations contain in themselves all the conditions which can arise in any proposed case of two reflexions.

101.

Corol. If $\psi = o$, or if the incident ray coincide with the principal section P C P, *i. e.* if the two reflexions both take place in the plane perpendicular to the reflecting surfaces, these formulæ take a very simple form, for we then have

$$\theta = o; \ \phi = 180°; \ \cos\alpha' = -\cos(\alpha + I)$$

that is $(\alpha + \alpha') = 180° - I$; and consequently $\cos(2\alpha + 2\alpha') = \cos(360° - 2I) = \cos 2I$, or $2\alpha + 2\alpha' = 2I$. But since $\theta = o$, we have by the last of the equations (A) $\cos D = \cos 2(\alpha + \alpha')$; consequently $D = 2\alpha + 2\alpha' = 2I$. That is to say, the deviation in this case, after two reflexions, is equal to twice the inclination of the reflecting planes, whatever be the original direction of the ray. This elegant property is the foundation of the common sextant and of the reflecting circle, and is commonly regarded as having been first applied to the measurement of angles by Hadley, though Newton appears also to have proposed it for the same object. See the explanation of these instruments.

Case where both reflexions are in one plane.

102.

In other cases, however, D, the deviation, is essentially a function of the angles expressing the position of the incident ray, and can only be obtained from the equations above stated.

103.

Proposition. Given the angles of incidence on the two planes, and the angle made by the plane of the first reflexion with that of the second; required the positions of the incident and twice reflected rays, the deviation of the ray after both reflexions, and the angle included between the reflecting surfaces.

Retaining the same notation, we have given, α, α' θ, required I, D, and ϕ, ψ.

1st, D is given at once, by the last of the general equations, (A.)

2ndly, To find the rest, put $x = \sin I$; $y = \sin\psi$; and $a = \sin\alpha' \,.\, \sin\theta$; put also $\cos\alpha = c$; $\sin\alpha = s$; $\cos\alpha' = c'$; $\sin\alpha' = s'$. We have then $xy = a$, or $y = \frac{a}{x}$; and the first of the equations (A) then gives

$$-c' = c\sqrt{1 - x^2} - s\sqrt{x^2 - a^2}$$

which, cleared of radicals and reduced, gives

$$o = x^4 + x^2\{2c'^2(c^2 \quad s^2) - 2c^2 - 2s^2a^2\} + (c'^2 - c^2)^2 + 2a^2s^2(c'^2 + c^2) + a^4s^4$$

and this equation, which, though biquadratic, is of a quadratic form, contains the general solution of the Problem.

104. Case when the planes of the two reflexions are at right angles.

Corol. 1. If $\theta = 90°$, or if the planes of the first and second reflexions be at right angles to each other, we have simply $\sin I \,.\, \sin\psi = \sin\alpha'$, and $a = \sin\alpha' = s'$.

In this case our final equation becomes

$$o = x^4 - 2x^2(1 - c^2c'^2) + (1 - c^2c'^2)^2$$

which, being a complete square, gives $x^2 = 1 - c^2c'^2$.

Now $x = \sin I$, therefore $x^2 = 1 - \cos I^2$, consequently we have the following simple result,

$$\cos I \; (= cc') = \cos\alpha \,.\, \cos\alpha'.$$

Or the cosine of the inclination of the planes to each other is equal to the product of the cosines of the angles of incidence on each. And, *vice versâ*, if this relation holds good, the planes of the two reflexions will necessarily be at right angles to each other; for, this relation being supposed, we have of course $x^2 = 1 - c^2 c'^2$, and therefore $1 - c^2 c'^2$ being put for x^2 in the general equation, the whole must vanish; now this substitution gives a biquadratic of a quadratic form for determining a, which must evidently be satisfied by taking

$$a = \sin a', \text{ and consequently } \theta = 90°.$$

This elegant property will be useful when we come to treat of the polarization of light.

105. *Corol.* 2. In the same case if $\theta = 90$, the deviation D is given by the equation

$$\cos D = \cos 2a \, . \, \cos 2a',$$

or, the cosine of the deviation is equal to the product of the cosines of the doubles of the angles of incidence.

106. *Problem.* A ray of light is reflected from each of two planes in such a manner that all the angles of incidence and reflexion are equal. Given the inclination of the planes, and the angles of incidence; required, first, the deviation; secondly, the inclination of the planes of the first and second reflexion to each other, and the angles made by each of these planes with the principal section of the reflecting planes.

Preserving the same notation we have $a = a'$, and therefore by the third of the equations (A) $\psi = \phi$, so that these equations become

$$\left.\begin{aligned} \cos a \,(1 + \cos I) &= \sin a \, . \, \sin I \, . \, \cos \psi \\ \sin a \, . \, \sin \theta &= \sin I \, . \, \sin \psi \\ \cos D = (\cos 2a)^2 &- (\sin 2a)^2 \, . \, \cos \theta \end{aligned}\right\} \qquad (a)$$

107. The first of these gives (putting for $1 + \cos I$ its value $2\left(\cos \frac{I}{2}\right)^2$ and for $\sin I$ its equal $2 \, . \sin \frac{I}{2} \, . \cos \frac{I}{2}$)

$$\cos \psi = \text{cotan}\, a \, . \, \text{cotan} \frac{I}{2}, \qquad (b)$$

whence ψ is immediately known. Hence ψ is had by the equation

$$\sin \theta = \frac{\sin I}{\sin a} \, . \, \sin \psi. \qquad (c)$$

Lastly, if we subtract each member of the third of the equations (a) from 1, divide both sides by 2, and reduce, we transform it into the following

$$\sin \frac{D}{2} = \sin 2a \, . \, \cos \frac{\theta}{2}. \qquad (d)$$

These equations afford ready and direct means of computing ψ, θ, and D in succession, from the known values of a and I; the formulæ are adapted to logarithmic evaluation, and are in themselves not inelegant.

§ IV. *Of Reflexion from Curved Surfaces.*

108. The reflexion of a ray from a curved surface is performed as if it took place at a reflecting plane, a tangent to the point of incidence. The reflected ray will therefore lie in the plane which contains the incident ray and the normal or perpendicular at the point of incidence. The general expressions for the course of the ray after reflexion at surfaces of double curvature being considerably complex, and not likely to be of great service to us in the sequel, we shall confine ourselves to the particular case of a surface of revolution (comprehending the cases of a plane, and conoidal surfaces of all kinds) where the plane of incidence is supposed to pass through the axis of revolution.

109. *Proposition.* A ray being incident on any surface of revolution in a plane passing through the axis, to find the direction of the reflected ray.

General investigation of the course of a ray reflected at any curve. Fig. 11.

Q P (fig. 11) being a section of the surface by the plane of incidence, Q N the axis, Q P the incident, and P r the reflected ray, which produced if necessary cuts the axis in q. Draw the tangent P T, the ordinate P M, and the normal P N, which produce to O, and put as follows,

$$x = QM\,; \; y = MP\,; \; p = \frac{dy}{dx}\,; \; \theta = \text{the angle } MQP,$$

or the angle made by the incident ray with the axis; then, since the angle of reflexion is equal to that of incidence, we have $\angle\, rPO = OPQ$, and therefore $NPq = OPQ$; consequently $QPT = TPq$. Now, $Qq = QM - Mq = QM - PM \, . \tan MPq$

$$= x - y \,.\, \tan\{\mathrm{TPM} - \mathrm{TP}q\}$$
$$= x - y \,.\, \tan\{\mathrm{TPM} - \mathrm{TPQ}\}$$
$$= x - y \,.\, \tan\{\mathrm{TPM} - \mathrm{PTM} + \mathrm{PQM}\}$$
$$= x - y \,.\, \tan\{90^\circ - 2\,\mathrm{PTM} + \mathrm{PQM}\}$$

But by the theory of curves we have $\tan \mathrm{PTM} = \frac{dy}{dx} = p$, consequently $\mathrm{PTM} = \text{arc} \tan p = \tan^{-1} p$, denoting by $\tan^{-1}$ the inverse function of that expressed by tan; and since $\mathrm{PQM} = \theta$, this expression becomes

$$\mathrm{Q}q = x - y \,.\, \mathrm{cotan}\{2 \,.\, \tan^{-1} p - \theta\}$$
$$= x - y \,.\, \mathrm{cotan}\left\{2 \,.\, \tan^{-1}\left(\frac{dy}{dx}\right) - \tan^{-1}\left(\frac{y}{x}\right)\right. \qquad (a)$$
$$\left(\text{Because } \tan\theta = \frac{\mathrm{PM}}{\mathrm{QM}} = \frac{y}{x}\right)$$

This then is the general expression for the distance between the points in which the incident and reflected rays cut the axis.

Now, by Trigonometry, we have (A and B being any two quantities)

$$\mathrm{cotan}\{2\tan^{-1}\mathrm{A} - \tan^{-1}\mathrm{B}\} = \mathrm{cotan}\left\{\tan^{-1}\frac{2\mathrm{A}}{1-\mathrm{A}^2} - \tan^{-1}\mathrm{B}\right\}$$
$$= \mathrm{cotan} \,.\, \tan^{-1}\left(\frac{2\mathrm{A} - (1-\mathrm{A}^2)\mathrm{B}}{(1-\mathrm{A}^2) + 2\mathrm{A}\mathrm{B}}\right)$$

that is, since $\mathrm{cotan} \,.\, \tan^{-1}\theta = \frac{1}{\theta}$, the cotangent and tangent being reciprocals of each other, simply

$$\frac{1 - \mathrm{A}^2 + 2\mathrm{A}\mathrm{B}}{2\mathrm{A} - (1-\mathrm{A}^2)\mathrm{B}}$$

Applying this to the present case, $\mathrm{A} = \frac{dy}{dx} = p$; $\mathrm{B} = \frac{y}{x}$, and therefore the expression above found for $\mathrm{Q}q$ becomes

$$\left.\begin{aligned} \mathrm{Q}q &= x - y \,.\, \frac{(1-p^2)x + 2py}{2px - (1-p^2)y} \\ &= 2 \,.\, \frac{(x+py)(px-y)}{2px - (1-p^2)y} \end{aligned}\right\} \qquad (b)$$

General expressions for the distance of the focus from the radiant point Q*q*.

These expressions contain the whole theory of the foci and aberrations of reflecting surfaces.

110. Angle made by the reflected ray and the axis.

Corol. 1. To find the angle made by the reflected ray with the axis, which we will call θ'. This is the angle $\mathrm{P}q\mathrm{M}$, which is the complement of $\mathrm{MP}q$. Now we have found above

$$\mathrm{MP}q = 90^\circ - 2\tan^{-1}p + \theta.$$

Hence

$$\theta' = 2 \,.\, \tan^{-1} p - \theta$$

But $\tan\theta = \frac{y}{x}$, so that substituting we have

$$\tan\theta' = \frac{2px - (1-p^2)y}{(1-p^2)x + 2py}; \qquad (c)$$

Corol. 2. $$\mathrm{A}q = a' = a + 2\,\frac{(x+py)(px-y)}{2px - (1-p^2)y}. \qquad (d)$$ 111.

112. In all the foregoing formulæ we have supposed the origin of the x placed at Q the radiant point. If we would place it elsewhere, as at A, we have only to write $x - a$ for x throughout. The formulæ then become on this hypothesis,

Formulæ when the radiant point is not in the origin of the coordinates.

$$\left\{\begin{aligned} \tan\theta &= \frac{y}{x-a} && (e) \\ \tan\theta' &= \frac{2p(x-a) - (1-p^2)y}{(1-p^2)(x-a) + 2py} && (f) \end{aligned}\right.$$

$$\left\{\begin{aligned} \mathrm{AQ} = a;\ \mathrm{Q}q &= \frac{2(x-a+py)(px-pa-y)}{2p(x-a) - (1-p^2)y} && (g) \\ \mathrm{A}q = a' &= \frac{2(x+py)(px-y) + \{(1-p^2)y - 2px\}a}{2px - (1-p^2)y - 2pa}; && (h) \end{aligned}\right.$$

113. Formulæ when the incident rays are parallel to the axis.

If the incident ray be parallel to the axis, we have only to suppose the point Q infinitely distant; or placing, as in the last article, the origin of the x at a point A at a finite distance, to make a (= A Q) infinite. The above expressions then give

$$Q\,q = \infty$$

$$\left.\begin{aligned} \tan\theta' &= \frac{2\,p}{1 - p^2} \\ A\,q &= x - y\,.\,\frac{1 - p^2}{2\,p} \end{aligned}\right\} \quad (i)$$

114. *Proposition.* To represent the incident and reflected rays by their equations.

The equation of any straight line is necessarily of the form $Y = \alpha\,X + \beta$. Suppose we take A for the common origin of the coordinates, and, retaining the foregoing notation, representing by x and y the coordinates of the point P in the curve, let X and Y represent those of any point in the incident ray; and, Q being the point in which that ray cuts the axis, and $A\,Q = a$, it is evident, first, that when $X = a$, $Y = o$; and secondly, since the ray passes through P, when $X = x$, $Y = y$. Hence we have

$$o = \alpha\,a + \beta, \quad \text{and} \quad y = \alpha\,x + \beta,$$

whence we get

$$\alpha = \frac{y}{x - a} \qquad \beta = -\,\frac{a\,y}{x - a}; \quad (1)$$

therefore, the equation of the incident ray is

$$Y = \frac{y}{x - a}\,(X - a); \quad (2)$$

or, which is the same in a different form,

$$Y - y = \frac{y}{x - a}\,(X - x); \quad (3)$$

or, since

$$\tan\theta = \frac{PM}{MQ} = \frac{y}{x - a},$$

$$Y = (X - a)\,.\,\tan\theta; \quad (4)$$

or, again,

$$Y - y = (X - x)\,.\,\tan\theta. \quad (5)$$

Similarly for the reflected ray, it is obvious that if we represent its equation by $Y = \alpha'\,X + \beta'$, we shall have

$$\alpha' = \frac{y}{x - a'} \qquad \beta' = -\,\frac{a'\,y}{x - a'}; \quad (6)$$

and consequently

$$Y = \left(\frac{y}{x - a'}\right).\,(X - a') = (X - a')\,.\,\tan\theta'; \quad (7)$$

$$Y - y = \frac{y}{x - a'}\,.\,(X - x) = (X - x)\,.\,\tan\theta'; \quad (8)$$

will be the corresponding forms of the equation of the reflected ray, in which a' and $\tan\theta'$ are given in terms of x, y, a, and $p = \frac{d\,y}{d\,x}$ by the equations (g) and (h) or (i).

115. Fig. 11. If the whole figure (fig. 11) be turned about the axis A M, and Q be supposed a radiant point, the rays in the whole conical surface generated by the revolution of Q P will be concentred after reflexion in one and the same point q, which will thus become infinitely more illuminated than by any single ray from an elementary molecule of the surface. The point P will generate an annulus, having M P for its radius; and q is called the *focus* of this annulus, and the distance A q the *focal distance* of the same annulus. This last expression is [illegible] commonly understood to mean the distance of q from the *vertex*, or point where the curve meets the axis, but we shall use it at present in the more general sense.

Focus. Focal distance. Vertex.

116. Generally speaking, then, the focus varies as the point P in the reflecting annulus varies, unless in that particular case where, by the nature of the curve, the function expressing a' is constant. Let us examine this case.

117. Investigation of the curves which reflect all the incident rays to one point.

Proposition. To find the curve which will have the same focus for every point in its surface of revolution, or on which rays diverging from or converging to any point Q, being incident, shall all after reflexion converge to or diverge from one point q.

The value of Q q assigned in Art. 109, E q, (b) being made constant, affords the equation

$$\frac{(x + p\,y)\,(p\,x - y)}{2\,p\,x - (1 - p^2)\,y} = \text{constant} = c.$$

This equation, cleared of fractions, and putting x for $x - c$, (which is merely shifting the origin of the coordinates to the distance c from their former origin) becomes

$$p\{x^2 - y^2 - c^2\} = (1 - p^2)\,x\,y. \qquad (a)$$

To integrate this equation, assume a new variable z, such that $p\,y = x\,z$, and (multiplying the original equation by y) we have

$$p y\,(x^2 - y^2 - c^2) = x\,y^2 - x\,.\,p^2\,y^2,$$

that is

$$x\,z\,(x^2 - y^2 - c^2) = x\,y^2 - x^3\,z^2,$$

whence we find

$$y^2 = \frac{z\,x^2 - z\,c^2 + z^2\,x^2}{1 + z} = x^2\,z - c^2\,.\,\frac{z}{1 + z}.$$

Differentiating this equation we get

$$\begin{aligned} 2\,y\,d\,y \left(= 2\,p\,y\,d\,x = z\,x\,z\,d\,x \text{ because } p = \frac{d\,y}{d\,x}\right) &\\ = d\left(x^2\,z - \frac{c^2\,z}{1 + z}\right) &\\ = 2\,x\,z\,d\,x + x^2\,d\,z - c^2\,d\,.\left(\frac{z}{1 + z}\right) & \end{aligned}$$

that is

$$x^2\,d\,z - c^2\,d\,.\,\frac{z}{1 + z} = o,$$

or

$$\left\{x^2 - \frac{c^2}{(1 + z)^2}\right\} d\,z = o. \qquad (b)$$

This equation may obviously be satisfied in two ways; the first is, by putting the factor

$$x^2 - \frac{c^2}{(1 + z)^2} = o, \quad \text{or } x = \pm\,\frac{c}{1 + z}$$

which gives (restoring the value of z, $z = \frac{p\,y}{x}$) merely $x + p\,y = c$; and, eliminating p between this and the original equation (a) we find, on reduction,

$$y^2 + (x - c)^2 = o.$$

This is, however, (as is clear from the way in which it has been obtained,) only a *singular solution* of the differential equation, (see Differential Calculus, *singular solutions;*) and as the value of y which results from it is always imaginary, it affords no curve satisfying the conditions of the problem.

The curve is in all cases a conic section.

The other way in which the equation (b) can be satisfied, is by putting $d\,z = o$, or $z =$ constant. Let this constant be represented by $-\,h$; then, since $z = \frac{p\,y}{x}$, we have

$$\frac{p\,y}{x} = \frac{y\,d\,y}{x\,d\,x} = -\,h,$$

which, integrated, gives

$$y^2 = h\,(a^2 - x^2),$$

a being another constant. This is the general equation to the conic sections, and it is obvious, from the properties of these curves, that they satisfy the conditions; because two lines drawn from their foci to any point in their periphery make equal angles with the tangent at that point, and, consequently, a ray proceeding from, or converging to, one focus, and reflected at the curve, must necessarily take a direction to or from the other. But, the foregoing analysis being direct, shows that they possess this property in common with no other curves.

118. Ellipse. Fig. 12.

Thus in the case of the ellipse, all rays, (fig. 12,) S P, S P′, &c. diverging from the focus S will after reflexion converge to the other focus H, the interior surface of the ellipse being polished; and all rays Q P, Q P′, &c. converging to S, will after reflexion diverge from H.

Fig. 13. 119. Hyperbola.

In the hyperbola, (fig. 13,) rays Q P, Q′ P, &c. converging to one focus S, and incident on the polished convex surface of the curve, will after reflexion converge to the other focus H; and if diverging from S, and reflected on the polished concave surface P P′, will after reflexion diverge from H.

120. Parabola. Fig. 14.

In the case of the parabola, rays parallel to the axis, incident on the interior or concave surface, will all be reflected to the focus S, fig. 14; and if reflected at the exterior or convex surfaces, will all after reflexion diverge from S.

121. Circle.

Rays converging to, or diverging from, the centre of a sphere will all after reflexion diverge from, or converge to, the same centre.

Let us now apply our general formula (b) (Art. 109) to some particular cases.

Proposition. Let the reflecting surface be a plane, or the curve P C a straight line. Required the focus of reflected rays.

122. Focus of a plane surface. Here we have $x = \text{constant} = a\ p = \frac{dy}{dx} = \infty$, and the general formula becomes simply

$$Qq = a' = \frac{2xy}{y} = 2x = 2a.$$

So that the focus of reflected rays is a point on the opposite side of the reflecting plane equally distant from it with the radiant point; and as this is independent of y, or of the situation of the point P, we see that all the rays after reflexion diverge from this point, see fig. 15.

123. Focus of a spherical annulus. *Proposition.* To find the focus of any annulus of a spherical reflector.

Let r be the radius of the sphere, and, if we fix the origin of the coordinates at the radiant point, the equation of the generating circle will be

$$r^2 = (x - a)^2 + y^2$$

This, differentiated, gives $$(x - a)\,dx + y\,dy = o,$$

consequently $$p = \frac{dy}{dx} = -\frac{x-a}{y};\ 1 - p^2 = \frac{2y^2 - r^2}{y^2}.$$

Hence, substituting in the general expression (b), we find for the focal distance the following value,

$$Qq = \frac{2a\{r^2 + a(x-a)\}}{r^2 + 2a(x-a)}; \qquad (a)$$

which expresses in all cases the distance of the focus of reflected rays from the radiant point.

For optical purposes, however, it is more convenient to know its distance from the centre, or from the surface.

The distance from the centre (Eq, fig. 16,) is

$$= Qq - QE = \frac{2a(ax - a^2 + r^2)}{2ax + r^2 - 2a^2} - a,$$

or $$Eq = \frac{ar^2}{2a(x-a) + r^2}; \qquad (b)$$

in which positive values of Eq lie to the right of E, or the same way with those of x or of Qq.

Focus for central rays in a spherical reflector. *Corol.* 1 If we would find the focus of the infinitely small annulus immediately adjoining to the *vertex* C, or C′ of the reflecting spherical surface, or, as it is termed in Optics, the *focus of central rays*, we must put in the case of the vertex C (when the reflexion takes place on a concave surface) $x = a + r$, and in the other case, viz. that where the rays are reflected on the convex surface C′, $x = a - r$. The former gives

$$Eq = \frac{ra}{2a + r};\ Cq = \frac{r(a+r)}{2a + r}; \qquad (c)$$

the latter gives the same results, writing only $-r$ for r.

124. If we bisect the radii C E and C′ E in F and F′, and suppose q and q' to be the foci of central rays reflected at C and at C′, we shall have

$$Fq = \tfrac{1}{2}r - \frac{ra}{2a + r} = \frac{\left(\frac{r}{2}\right)^2}{a + \frac{r}{2}}, \qquad (d)$$

which gives the following useful analogy,

$$QF : FE :: EF : Fq. \qquad (e)$$

Similarly we have QF′ : F′E : : EF′ : F′q; so that the same analogy applies to both cases, and may be regarded as the fundamental proposition in the theory of the foci for central rays. For it is obvious, that if P C were any other curve than a circle, the same must hold good, taking only E the centre of curvature at the vertex.

125. Principal focus. *Corol.* 2. If a be infinite, or the incident rays be parallel, we have F$q = o$, which shows that the *focus of central parallel rays* bisects the radius. This focus, for distinction's sake, is called the *principal focus* of the reflector.

126. Conjugate foci. *Definition.* Q and q are termed *conjugate foci.* It is evident that if q be made the radiant point, Q will be its focus; for the rays will pursue the same course backwards.

127. *Corol.* 3. Regarding only central rays: the conjugate foci move in opposite directions, and coincide at the centre and surface of the reflector.

For let a vary from ∞ to $-\infty$, then Fq will vary as follows: first, while a varies from ∞ to $-\frac{r}{2}$F, q is

§ V. *Of Caustics by Reflexion, or Catacaustics.*

134. If rays of light be incident on a medium of any other form than that of a conic section, having the radiant point in the focus, they will after reflexion no longer converge to or diverge from any one point, but will be dispersed according to a law depending on the nature of the reflecting curve; the inclination of each reflected ray to the axis varying according to the point of the curve from which it is reflected, and not being the same for any two consecutive rays. Of course each ray will intersect that immediately consecutive to it in some point or other, and the *locus* of these points of continual intersection will trace out a curve to which the reflected rays will all necessarily be tangents, and which is called *a caustic*. If these rays fall on another reflecting curve, they will be again dispersed, and another caustic will originate in the continual intersections of the consecutive rays of the former, and so on to infinity.

Caustics by reflexion defined.

135. Let Q P, Q′ P′, (fig. 18,) be any two contiguous rays incident on consecutive points P, P′ of a reflecting curve P P′, and after reflexion let them pursue the courses P R, P′ R′; and since they are not necessarily parallel, let Y be their point of intersection, then will Y be the point in the caustic Y Y′ Y″ corresponding to the point P in the reflecting curve; and if we determine the points Y′ Y″, &c. from the consecutive points P′ P″, &c. in the same manner, the locus of these, or the curve Y Y′ Y″ will be the whole caustic.

Fig. 18.

136. Since the reflected ray passes through P, whose coordinates are $x\,y$, its equation, as we have already seen (Art. 114), is necessarily of the form

Coordinates of the caustic investigated on any supposition of the law of divergence.

$$Y - y = P(X - x)$$

If we regard x, y, P as variable, this will represent any one of the reflected rays P R, and the consecutive ray P′ R′ will be represented by

$$Y - (y + dy) = (P + dP)\,(X - (x + dx))$$

Now since the point Y in which these two rays intersect is common to both, the coordinates X and Y at this point are the same for both; and therefore at this point both these equations coexist, and thereby determine the values of X and Y, or the situation of the point Y. Now the latter of these equations is nothing more than the former *plus* its differential, on the supposition of X and Y remaining constant. Therefore, we have to find X and Y from the two equations,

$$Y - y = P\,(X - x)$$

$$-\,dy = (X - x)\,dP - P\,dx,$$

which gives at once

$$\left.\begin{aligned} X &= x + \frac{P - p}{dP}\,dx \\ Y &= y + P\,.\,\frac{P - p}{dP}\,dx \end{aligned}\right\} \quad (k)$$

In these equations we have only to substitute for P its value $= \tan\theta'$, or $\dfrac{2p\,(x - a) - (1 - p^2)\,y}{(1 - p^2)\,(x - a) + 2py}$; and after executing all the differentiations indicated, or implied, to eliminate x and y by the equations of the curve and the other conditions to which the quantity a may be subjected, an equation between X and Y will result which will be the equation of the caustic.

137. *Proposition.* To determine the caustic when rays diverge from one fixed point in the axis of a given reflecting curve.

Caustic when rays diverge from a fixed point.

In this case a is invariable, and the differentiation of P must be performed on this hypothesis. It will, therefore, simplify the question if we put $a = o$; or suppose the origin of the coordinates in the radiant point, in which case

$$\left.\begin{aligned} P &= \frac{2px - (1 - p^2)\,y}{2py + (1 - p^2)\,x} \\ \frac{dP}{dx} &= (1 + p^2)\,.\,\frac{(1 + p^2)\,(y - px) + 2q\,(x^2 + y^2)}{\{2py + (1 - p^2)\,x\}^2} \\ \text{Where} \qquad q &= \frac{dp}{dx} \\ P - p &= \frac{(1 + p^2)\,(px - y)}{2py + (1 - p^2)\,x} \end{aligned}\right\} \quad (l)$$

which substituted, we find

$$\left.\begin{aligned} X &= 2 \, . \, \frac{p\,(p\,x-y)^2 - q\,x\,(x^2+y^2)}{(1+p^2)\,(p\,x-y) - 2\,q\,(x^2+y^2)} \\ Y &= 2 \, . \, \frac{(p\,x-y)^2 + q\,y\,(x^2+y^2)}{-(1+p^2)\,(p\,x-y) + 2\,q\,(x^2+y^2)} \end{aligned}\right\} \quad (m)$$

Corol. 1. If the incident rays be parallel, or the radiant point at an infinite distance, we may fix the origin of the coordinates where we please; and since in this case the equation of any reflected ray is, by 113 equation (*i*) and 114 equation (8), 138. Caustic for parallel rays.

$$Y - y = (X - x) \, . \, \frac{2\,p}{1-p^2} \qquad (m, 2)$$

we have

$$P = \frac{2\,p}{1-p^2}; \; P - p = \frac{p\,(1+p^2)}{1-p^2}; \; \frac{d\,x}{d\,P} = \frac{(1-p^2)^2}{2\,q\,(1+p^2)}$$

putting q for $\frac{d\,p}{d\,x}$ or $\frac{d^2\,y}{d\,x^2}$.

These substitutions made, we get the following values for the coordinates of the caustic,

$$X = x + \frac{p}{2\,q}\,(1-p^2); \; Y = y + \frac{p^2}{q}. \qquad (n)$$

Corol. 2. In the general case, if we put $f =$ the line P y, or the distance between the point in the curve and the corresponding point in the caustic we have 139. Distance between corresponding points in curve and caustic

$$f = \sqrt{(X-x)^2 + (Y-y)^2}$$

Which, if we write for $X - x$ and $Y - y$, their values above found become

$$f = \sqrt{1+P^2} . \; \frac{P-p}{d\,P}\, d\,x \qquad (o)$$

or, writing for P its value, and executing the operations,

$$f = \frac{-(y-p\,x)\,(1+p^2)\,\sqrt{x^2+y^2}}{(y-p\,x)\,(1+p^2) + 2\,q\,(x^2+y^2)}. \qquad (p)$$

Corol. 3. In the case of parallel rays, when 140.

$$P = \frac{2\,p}{1-p^2}; \; \frac{d\,P}{d\,x} = \frac{2\,q\,(1+p^2)}{(1-p^2)^2}; \; P - p = \frac{p\,(1+p^2)}{1-p^2}; \; \sqrt{1+P^2} = \frac{1+p^2}{1-p^2}$$

we have

$$f = \frac{p\,(1+p^2)}{2\,q}. \qquad (q)$$

Corol. 4. Call c the chord of the circle of curvature passing through the origin of the coordinates, or through the radiant point: then, by the theory of curves, 141.

$$c = \frac{2\,(p\,x-y)\,(1+p^2)}{q\,\sqrt{x^2+y^2}}$$

so that

$$q\,(x^2+y^2) = \frac{2\,(p\,x-y)\,(1+p^2)\,\sqrt{x^2+y^2}}{c}$$

and substituting this for $q\,(x^2+y^2)$, in the general expression for f, we eliminate q, and get

$$f = \frac{c\,\sqrt{x^2+y^2}}{4\,\sqrt{x^2+y^2} - c} = \frac{r\,c}{4\,r - c}$$

putting

$$r = \sqrt{x^2+y^2}.$$

Hence we have

$$f - \tfrac{1}{4}\,c = \frac{(\frac{1}{4}\,c)^2}{r - \frac{1}{4}\,c}$$

which gives

$$r - \tfrac{1}{4}\,c : \tfrac{1}{4}\,c :: \tfrac{1}{4}\,c : f - \tfrac{1}{4}\,c. \qquad (r)$$

Hence the following general property. (Smith's *Optics*, ed. 1738, p. 160.) 142.

Q and q being two conjugate foci of an elementary pencil of rays reflected at any curve surface at P, fig. 19. Let V P W be the circle of curvature; (if the curve be a circle, this will be the curve itself.) Let the chords Fig. 19.

General relation between conjugate points or foci of reflected rays incident on any curve.

PV, PW in the direction of the incident and reflected rays be divided in F, f, so that PF and Pf shall each be one quarter of the whole chords, and the relation between Q and q will be expressed by the proportion

$$QF \cdot FP :: Pf : fq. \qquad (s)$$

143. *Corol.* 5. Putting $\frac{P-p}{dP} dx = M$, we have $\frac{dX}{dx} = 1 + \frac{dM}{dx}$;

$$\frac{dY}{dx} = p + P\frac{dM}{dx} + M\frac{dP}{dx} = P\left(1 + \frac{dM}{dx}\right)$$

Hence it follows that $P = \frac{dY}{dX}$;

P therefore is to the caustic, for the coordinates X, Y, what p is to the reflecting curve for the corresponding point whose coordinates are x, y.

144. Length of the caustic investigated.

Corol. 6. If we put S for the length of the caustic

$$= \text{the arc AHKY, we have } dS = \sqrt{dX^2 + dY^2}$$

or

$$dS = dX . \sqrt{1+P^2} = (dx + dM)\sqrt{1+P^2}$$

$$dx . \sqrt{1+P^2} + df - M . \frac{PdP}{\sqrt{1+P^2}}$$

because $df = d . M . \sqrt{1+P^2} + M . \frac{PdP}{\sqrt{1+P^2}}$; but $MdP = (P-p)dx$

so that we have

$$dS = df + dx\left\{\sqrt{1+P^2} - \frac{(P-p)P}{\sqrt{1+P^2}}\right\}$$

$$= df + dx . \frac{1+Pp}{\sqrt{1+P^2}};$$

that is, substituting for P its value $\frac{2px - (1-p^2)y}{2py + (1-p^2)x}$,

$$dS = df + dx . \frac{x+py}{\sqrt{1x^2+y^2}} = df + d . \sqrt{x^2+y^2}$$

and integrating $S = \text{constant} + f + \sqrt{x^2+y^2}$.

Caustics always rectifiable.

Hence it follows, that the caustic is always a rectifiable curve, and its

$$\left.\begin{array}{l} \text{Length AK}y = QP + Py + \text{constant} \\ \text{Arc AKF} = QC + CF + \text{constant} \end{array}\right\} \text{consequently, subtracting}$$

But

$$\text{Arc F}y = (QC + CF) - (QP + PY).$$

Hence it appears, that the caustic is necessarily a rectifiable curve when the reflecting curve is not itself transcendental.

145. Fig. 20.

If the rays PR, P′R′, P″R″, &c. after reflexion at the curve PP′P″ fall on another reflector RR′R″ and are reflected in the directions RS, R′S′, R″S″, &c. (fig. 20) their continual intersections will form another caustic ZZ′Z″, and so on *ad infinitum*, which may be determined by a similar analysis. In like manner, whatever be the law according to which the rays QP, Q′P′, &c. are dispersed, we may conceive each to be a tangent to a curve which may be regarded as the caustic of another reflecting curve, and so on. Let VV′V″ be this curve. Since PVQ is a tangent to it, if this curve and the curve PP′P″ be given, the point Q in the axis from which the incident ray QP may be regarded as radiating, is determined in terms of the coordinates of P, and therefore the quantity a may be eliminated altogether. The manner of doing this is shown in the following

146. General relation between two conjugate caustics and their intermediate reflecting curve investigated.

Proposition. To determine the relations between any two consecutive, or, as they may be termed, *conjugate* caustics VV′V″, YY′Y″, and the intermediate reflecting curve PP′P″.

Let V and Y be, as before, any two conjugate points in the caustics, P the reflecting point; then if we put

ξ and η for the coordinates of V

x and y for those of P

X and Y of Y

Since the line P V Q is a tangent to the first curve at V, we must evidently have

$$y - \eta = \frac{d\,\eta}{d\,\xi}\,(x - \xi)$$

and this, combined with the equation between η and ξ, which represents the curve V V′ V″ suffices to determine η and ξ in terms of x, y, or *vice versâ*, x and y in terms of ξ and η.

Again, we have also by Art. 114, equation (2)

$$y - \eta = \frac{y}{x - a}\;(x - \xi)$$

and consequently

$$x - a = y\,.\frac{x - \xi}{y - \eta}\,;\quad a = \frac{\xi\,y - \eta\,x}{y - \eta}.$$

Thus a is given in terms either of x, y, or of η, ξ, whichever we may prefer. It only remains to substitute this in the value of P.

$$\mathrm{P} = \frac{2\,p\,(x - a) - (1 - p^2)\,y}{(1 - p^2)\,(x - a) + 2\,p\,y}$$

which thus becomes

$$\mathrm{P} = \frac{2\,p\,(x - \xi) - (1 - p^2)\,(y - \eta)}{(1 - p^2)\,(x - \xi) + 2\,p\,(y - \eta)}\,; \qquad (t)$$

and this, being free of a, may be substituted in the equations (k) Art. 136, when X and Y will be at once obtained in terms of x, y, ξ, η, the coordinates of the reflecting curve and the preceding caustic.

We shall now proceed to illustrate the theory above delivered by an example or two.

Required the caustic when the reflecting curve is a cycloid, and the incident rays are parallel to each other and to the axis of the cycloid. 147.

Caustic of a cycloid.

The equation of the cycloid is

$$\frac{d\,y}{d\,x} = p = \frac{\sqrt{x}}{\sqrt{2 - x}}$$

taking unity for the radius of the generating circle.

From this we get

$$\frac{1}{q}\,(2 - x)\,\sqrt{2\,x - x^2}$$

and therefore

$$\frac{p}{q} = 2\,x - x^2\,;$$

consequently, by the equations (k) of Art. 136, we shall have

$$\mathrm{X} = x + \frac{1 - p^2}{2}\,.\,\frac{p}{q} = 2\,x - x^2$$

$$\mathrm{Y} = y + p\,.\,\frac{p}{q} = y + x\,\sqrt{2\,x - x^2}$$

whence

$$\frac{d\,\mathrm{Y}}{d\,x} = p + \frac{\sqrt{x}}{\sqrt{2 - x}}\,(3 - 2\,x) = 2\,\sqrt{2\,x - x^2} = 2\,\sqrt{\mathrm{X}}$$

Now we have also

$$\frac{d\,\mathrm{X}}{d\,x} = 2\,(1 - x)$$

But since $\mathrm{X} = 2\,x - x^2$, we have $1 - x = \sqrt{1 - \mathrm{X}}$, and therefore

$$\frac{d\,\mathrm{X}}{d\,x} = 2\,\sqrt{1 - \mathrm{X}}$$

So that we have, finally,

$$\frac{d\,\mathrm{Y}}{d\,\mathrm{X}} = \sqrt{\frac{\mathrm{X}}{1 - \mathrm{X}}}$$

which shows that the caustic is itself a cycloid of half the linear dimensions of the reflecting curve. Is itself a cycloid.

To take one other example, let us suppose the reflecting curve a circle, and the radiant point infinitely distant. Here we have (placing the origin of the coordinates in the centre) 148.

$$x^2 + y^2 = r^2;\ p = -\frac{x}{\sqrt{r^2 - x^2}};\ q = -\frac{r^2}{(r^2 - x^2)^{\frac{3}{2}}},$$

Caustic of a circle.

consequently, by the equations (*k*) of Art. 136

$$\left.\begin{aligned} X &= x + \frac{p\,(1 - p^2)}{2\,q} = \frac{3\,r^2 - 2\,x^2}{2\,r^2}\;x \\ Y &= y + \frac{p^2}{q} = \frac{(r^2 - x^2)^{\frac{3}{2}}}{r^2} = \frac{y^3}{r^2} \end{aligned}\right\};\qquad (u)$$

Then since (supposing, for brevity, $r = 1$, which will not affect the result)

$$4\,X^2 = 9\,x^2 - 12\,x^4 + 4\,x^6$$

$$4\,Y^2 = 4 - 12\,x^2 + 12\,x^4 - 4\,x_6$$

Adding, $$4\,(X^2 + Y^2) = 4 - 3\,x^2;\ x^2 = \frac{4}{3}\,(1 - X^2 - Y^2)$$

So that we get, finally, substituting this value of x^2 in that of Y, and reducing,

$$(4\,X^2 + 4\,Y^2 - 1)^3 = 27\,Y^2;\qquad (v)$$

which is the equation of the caustic.

This equation belongs to an epicycloid generated by the revolution of a circle whose radius is ¼ that reflecting circle on another concentric with the latter, and whose radius is ½ that of the reflecting

Fig. 21. Fig. 21 represents the caustic in this case; Q P being the incident ray, and P Y the reflected. It has at F, which is the principal focus of rays reflected at the concave surface B C D, and another at F′, w that of the rays reflected from the convex surface B A D. In the latter case, it is not the rays then but their prolongations backwards which touch the caustic.

149. *Corol.* When y is very small, or immediately adjacent to the cusp F, the form of the caustic app indefinitely to that of a semicubical parabola. For, generally,

$$X = \tfrac{1}{2}\sqrt{1 + 3\,Y^{\frac{2}{3}} - 4\,Y^2},$$

and when Y is very small, neglecting Y^2 in comparison with $Y^{\frac{2}{3}}$

$$X = \frac{1}{2} + \frac{3}{4}\,Y^{\frac{2}{3}},\ \text{or}\ Y^2 = \left(\frac{4}{3}\right)^3 \cdot \left(X - \frac{1}{2}\right)^3;\qquad (w)$$

150. It is, as we have seen, only in certain very particular cases, when rays proceeding from one point and r at a curve proceed after reflexion all to or from one point. In general they are distributed in the described in Art. 145, 146, being all tangents to the caustic. The density of the rays therefore in any point caustic is infinitely greater than in the space surrounding it, and in the space between the caustic and flecting curve (P C F Y, fig. 18) is greater than in the space without the caustic Q Y F. This is obvi in the latter space only the incident rays occur, while in the former are included all the reflected rays as the incident ones.

151. Fig. 22. This may be easily shown experimentally, in a very satisfactory manner pointed out by Dr. Brews bending a narrow strip of polished steel into any concave form, as in fig. 22, and placing it upright on of white paper. If in this state it be exposed to the rays of the sun, holding the plane of the paper s pass nearly but not quite through the sun, the caustic will be seen traced on the paper, and marked by bright well-defined line; the part within being brighter than that without, and the light graduating aw the caustic inwards by rapid gradations. If the form of the spring be varied, all the varieties of catac with their singular points, cusps, contrary flexures, &c. will be seen beautifully developed. The experin at once amusing and instructive.

The bright line seen on the surface of a drinking-glass full of milk, or, better still, of ink, standing in su is a familiar instance of the caustic of a circle just investigated.

152. If the figure 18 be turned round its axis, the reflecting curve will generate a surface of revolution, w supposed polished within or without, as the case may be, will become *a mirror*. The caustic will also g a conoidal surface, to which all the rays reflected by the mirror will be tangents. No mirror, therefore, is not formed by the revolution of a conic section having the radiant point in its focus, can converge reflected rays to one point or *focus*. There will, however, always be one point which receives the reflecte in a more dense state than any other. This point is the cusp F, as we shall presently see. The devia any reflected ray from this point is what is termed its *aberration*.

153. The concentration and dispersion of rays by reflecting and refracting surfaces forming the great busi *practical optics*, it will be necessary to enter at large into this subject; and, first, it will be proper to i how far any given reflector will enable us to concentrate the rays which fall on it. To this end let the fol problem be proposed.

154 *Proposition.* A reflector of any figure, of a given diameter or *aperture* A B, being proposed, to find th *of least aberration*, or the place where a screen must be placed to receive all the rays reflected from the s within the least possible circular space (since they cannot be all collected in one point) and the diameter circle.

Fig. 23.

A C B (fig. 23) being the mirror, Q the radiant point, G K fkg the caustic, f the cusp or focus for central rays, q the focus of the extreme rays A q, B q, produce these lines till they cut the caustic in Y y. It is clear, then, since all the rays reflected from the portion A C B of the reflector are tangents to points of the caustic between K, f and k, f, that they must all pass through the line Y y. Retaining the notation of the foregoing propositions, (*i. e.* supposing $Q\,x = X$; $X\,y = Y$.) Let us put $Q\,L = \overset{\circ}{X}$, $L\,K = \overset{\circ}{Y}$, $Q\,D = \overset{\circ}{x}$; $D\,A = \overset{\circ}{y}$; and let $\overset{\circ}{P}$, $\overset{\circ}{p}$ represent the values of P and p corresponding to the points K and A of the caustic and reflecting curves. The equation of the line A K $q\,y$ will then be

$$Y - \overset{\circ}{y} = \overset{\circ}{P}(X - \overset{\circ}{x}); \qquad (x)$$

Y and X being the coordinates of any point in it. But at the point y, where it cuts the other branch of the caustic, these coordinates are common to the straight line, and to the caustic. At this point, therefore, the above equation, and those expressing the nature of the caustic, must subsist together. Now these are the equations (k) Art. 136, combined with the original equation of the reflecting curve. Eliminating, then, x and y, by the aid of two of them, and determining the values of X, Y from the rest, the problem is resolved.

155. Now the same equation which gives the value of y, or $x\,y$, must also give that of L K, because K is a point in both caustic and the line A K y, as well as y. But, moreover, since A K y is a tangent, the point K is a double point; therefore the final equation in Y must necessarily have two equal roots, besides the value of Y sought; and these being known, the other may be found from a depressed equation.

The method here followed is, apparently, different from that usually employed, which consists in making the value of y as determined by the intersection of the extreme reflected ray A K y, and any other reflected ray (from P) a maximum. But the difference is only apparent, for in the latter method we have to make Y as determined by the two equations (holding good jointly)

$$Y - \overset{\circ}{y} = \overset{\circ}{P}\,(X - \overset{\circ}{x}), \text{ and } Y - y = P\,(X - x)$$

a maximum, or $d\,Y = o$. Now in this case the former equation gives $d\,X = o$ also; and therefore, differentiating the latter, we have

$$-\,d\,y = (X - x)\,d\,P - P\,d\,x,$$

whence

$$X - x = \frac{P - p}{d\,P}\,d\,x$$

and therefore

$$Y - y = P\,.\,\frac{P - p}{d\,P}\,d\,x.$$

Now these are nothing more than the equations of Art. 136, expressing the general properties of the caustic; so that this consideration of the maximum only leads by a more circuitous route to the same equations as the method above stated, and is in fact nothing more than a different mode of expressing the caustic.

156. Circle of least aberration in a spherical reflector.

Let us apply this reasoning to the case when the reflector is spherical. Resuming the equations and notation of Art. 148, and putting a for the extreme value of y, or the *semi-aperture* of the mirror, and b for the corresponding value of x, that of P will be

$$\left(\frac{2\,p}{1 - p^2} =\right) = \frac{2\,a\,b}{b^2 - a^2} = \frac{2\,a\,b}{1 - 2\,a^2}.$$

Hence the equation (m, 2) Art. 138, of the extreme reflected ray becomes

$$Y - a = \frac{2\,a\,b}{1 - 2\,a^2}\,(X - b)$$

whence we get

$$2\,X = \frac{1}{b}\left(1 + \frac{1 - 2\,a^2}{a}\,.\,Y\right)$$

Assume z, so that $Y = a^3\,z^3$, z being another unknown quantity, then we have

$$4\,X^2 = \frac{1}{1 - a^2}\,\{1 + (1 - 2\,a^2)\,a^2\,z^3\}^2.$$

Substituting this for $4\,X^2$, and for Y^2 its value $a^6\,z^6$ in the equation of the caustic (v) Art. 148, extracting the cube root, and reducing, we get the following equation for finding z,

$$a^2\,z^6 + (2 - 4\,a^2)\,z^3 + (3\,a^2 - 3)\,z + 1 = o.$$

Now this, according to the remark in Art. 155, must have two equal roots, viz. when $x = b$, or $Y = a^3$, that is, when $z = 1$. Hence this equation must necessarily be divisible by $(z - 1)^2$. Performing the division we find it is so, and the quotient gives

$$a^2\,z^4 + 2\,a^2\,z^3 + 3\,a^2\,z^2 + 2\,z + 1 = o; \qquad (y)$$

for determining the remaining values of z.

As this investigation is rigorous, nothing having been omitted or neglected as small, we have here the complete solution of the problem, whatever be the aperture of the mirror. If this be supposed small in

157. Case when the aperture is moderate.

comparison with the radius, an approximation to the value of z will be had by the series thence derived,

$$z = -\frac{1}{2} - \frac{9}{32}a^2 - \frac{9}{32}a^4 - \frac{1395}{4096}a^6 - \&c.$$

and of course since $Y = a^3 z^3$,

$$Y = -\frac{a^3}{8} - \frac{27}{128}a^5 - \frac{675}{2048}a^7 - \&c. \qquad (z)$$

158. Case where the aperture is small when compared to radius.

The first term of this series is sufficient for most cases which occur in practice, and gives

$$Y = -\frac{a^3}{8} \qquad (\alpha)$$

or, supposing r the radius of curvature of the reflector,

$$Y = -\frac{a^3}{8r^2} \qquad (\beta)$$

The lateral aberration corresponding to the semi-aperture a is, by the equation (j), Art. 133, equal to $\frac{a^3}{2r^2}$; consequently, in the case of small apertures, the radius of the least circle of aberration is equal to $\frac{1}{4}$ of the lateral aberration (at the focus) of the exterior annulus.

159. *Corol.* The least circle of aberration is nearer the mirror than its principal focus, by $\frac{3}{4} fg$ or $\frac{3}{4}$ the longitudinal aberration $= \frac{3}{16} \cdot \frac{a^2}{r}$.

160. Density of reflected rays at any point investigated. Fig. 24.

To complete the theory of caustics, it only remains to examine the degree of concentration of the reflected rays at any assigned point. To this end, let S (fig. 24) be any point, and through it let $PSYq$ be drawn touching the caustic in Y. Then S may be regarded as lying in a conical surface generated by the revolution of the tangent $PYsq$, about the axis; and all the rays in the annulus, generated by the revolution of the element PP', will be contained in the hollow conoidal solid formed by the revolution of the figure $PP'Yq'q$ about the same axis. Hence at S the rays will be concentrated: first, in a plane parallel to that of the paper, in the ratio of PP' to SS', or PY to SY; and, secondly, in a plane perpendicular to that of the paper, or in the ratio of the circumferences of the circles generated by the revolution of P and of S, that is, in the ratio of these radii $PM : ST$. On both accounts, therefore, the concentration at S will be represented by $\frac{PM}{ST} \times \frac{PY}{SY}$, or $\frac{Pq}{Sq} \times \frac{PY}{SY}$. If, therefore, we represent by 1 the density of the rays immediately on their reflexion at P, their density at S corresponding, will be represented by $\frac{PY \cdot Pq}{SY \cdot Sq}$, and this is true, whatever be the situation of S.

161. 1st case. But there are now several cases to be distinguished. First, when S is situated in any part of the spaces KHV, NDW, no such tangent can be drawn to cut the reflector within its aperture AB; therefore these spaces receive no rays at all, and the density $= o$ in every point.

162. 2nd case. Secondly, when S is situated anywhere within the spaces AGB, VHFE, EFDW, only one such tangent can be drawn to cut the reflecting curve between A and B. So that in these spaces the density is simply represented by

$$D = \frac{PY \cdot Pq}{SY \cdot Sq}.$$

163. 3rd case. Thirdly, within the spaces KGH and MGD two tangents can be drawn from any point S, both touching the branch Fk on the same side of the axis as the point S. If we suppose $P_1 Y_1 S q_1$ and $P_2 Y_2 S q_2$ to be these tangents, S will receive rays belonging to both these converging conoids, and the density will therefore be the sum of those belonging to either, or

$$D = \frac{PY_1 \cdot Pq_1}{SY_1 \cdot Sq_1} + \frac{PY_2 \cdot Pq_2}{SY_2 \cdot Sq_2}.$$

Fig. 25. See fig. 25.

164. 4th case. Fourthly and lastly, within the space FHGD there may be drawn three tangents $q_1 S Y_1 P_1$, $q_2 S Y_2 P_2$, and $q_3 S Y_3 P_3$, all falling within AB, the two first (fig. 26) touching the branch Fk on the same side as S, the

177. Let A C B (fig. 23) be the refracting surface, P C p the perpendicular to it at the point of incidence C, S C the incident, and C s the refracted ray. Then we shall have

Fig. 23.

$$\sin PCS : \sin pCs :: \mu : 1,$$

μ being a constant quantity; that is, constant for the same medium A B, though its value is different for different media.

178. It is usual, for brevity, to speak of the sine of incidence, and the sine of refraction, instead of the sines of the angle of incidence, and the angle of refraction.

179. The numerical value of the quantity μ, or of $\frac{\text{sin of incidence}}{\text{sin of refraction}}$ in any medium, must be ascertained before the law of refraction in that medium can be regarded as perfectly known. This may be done experimentally by actually measuring the angle of refraction corresponding to any one given angle of incidence, for the value of the above fraction being thus determined for one incidence holds equally for every other, or by other more easy or more refined modes to be described hereafter. This quantity μ is called the *index* of refraction of the medium A B.

Index of refraction.

180. The medium in which the ray proceeds previous to its incidence on A B is here regarded as a vacuum. If the medium A B be also a vacuum, it is clear that the ray will not change its course; so that the angle of incidence will equal that of refraction, and the value of μ will be equal to 1. This is the lowest value of μ, as no medium has yet been discovered which refracts rays *from* the perpendicular when incident from a vacuum. The greatest value of μ yet known is 3, when the refraction is made into chromate of lead; and between these limits almost every intermediate gradation has been found to belong to some one or other transparent body. Thus for air at its ordinary density $\mu = 1.00028$, while for water it is 1.336, for ordinary crown glass 1.535, for flint glass 1.60, for oil of cassia 1.641, for diamond 2.487, and for the greatest refraction of chromate of lead 3.0.

181. It is a general law in Optics, that the visibility of two points from one another is mutual, whatever be the course pursued by the rays which proceed from one to the other. In other words, that if a ray of light proceeding from A arrives by any course at B, however often reflected, refracted, &c., a ray can also arrive at A from B by retracing precisely the same course in a contrary direction. It follows from this, that if the ray S C incident on the exterior surface of a medium A B, (fig. 23,) pursue after refraction the course C s, then will a ray s C, incident on the exterior surface of the medium, be refracted out of it in the direction C S, being bent *from* the perpendicular. Consequently, since in this case the angle of incidence is the same with the angle of refraction in the former case, and *vice versâ*, we shall have here $\frac{\text{sin incidence}}{\text{sin refraction}} = \frac{1}{\mu}$. Thus we see that the index of refraction *out* of any medium into vacuum is the reciprocal of the index of refraction *into* the medium from the vacuum.

Refraction out of any medium into vacuum.

182. Hence it follows, that a ray can be intromitted into any medium from a vacuum at any angle of incidence; for since sin refr. $= \sin pcs = \frac{1}{\mu} . \sin PCS$, the value of μ being greater than 1, the sine of pcs will necessarily be less than that of P C S, and of course less than unity; so that the angle of refraction can never become imaginary. Thus, as the angle of incidence P C S increases from o, or as the ray S C becomes more and more oblique to the surface till it barely grazes it, as at S″ C, the refracted ray becomes also more oblique, but much less rapidly, and never attains a greater obliquity than the situation C s'', in which $\sin pCs'' = \frac{\sin 90^\circ}{\mu} = \frac{1}{\mu}$. This limiting angle, then, is the maximum angle of refraction from vacuum into the medium, and its value in any given medium is found by computing the angle whose sine is the reciprocal of the index of refraction. Thus in water the angle of refraction cannot exceed arc $\sin \frac{1}{1.336}$, or 48° 27′ 40″. In crown glass the limit is 40° 39′, in flint 38° 41′, in diamond 23° 42′, while for the greatest refraction of chromate of lead the limit is so low as 19° 28′ 20″.

Limit of the angle of refraction.

183. Conversely, when a ray is incident on the interior surface of the medium, at any angle less than the limiting angle whose sine is $\frac{1}{\mu}$, it will be refracted and emerge according to the law laid down in Art. 181, being bent *from* the perpendicular. But as the angle of incidence p C s increases, the angle of refraction P C S increases more rapidly; and when the former angle has reached the limiting value p C s'', the transmitted ray emerges in the direction C S″, barely grazing the external surface. If the angle of incidence be still further increased, the angle of refraction becomes imaginary; for we have $\sin PCS = \mu \times \sin pCs$, and if $\sin pCs > \frac{1}{\mu}$, the sine of P C S must be greater than unity. This shows that the ray cannot emerge; but it does not inform us what becomes of it. To ascertain this, we must have recourse to experiment; from which we learn, that after this limit is passed, the ray, instead of being refracted out of the medium, is turned back and *totally reflected* within it, making the angle of reflexion $pCS''' = pCs''$.

Limit to the possibility of a ray's egress from any medium.

When the ray cannot emerge it is reflected.

$$\sin SBP : \sin EBp = \sin BEQ :: \mu : 1$$

$$\sin RHE = \sin qEH : \sin rHT = \sin PBS :: 1 : \mu,$$

and, compounding these proportions,

$$\sin HEq : \sin BEQ :: \mu : \mu' ; \quad \frac{\sin BEQ}{\sin HEq} = \frac{\mu'}{\mu}.$$

Absolute and relative indices of refraction.

But B E Q is the angle of incidence, and H E q that of refraction, at the common surface of the media, consequently the *relative* index, or index of refraction from the first into the second, is equal to the quotient $\frac{\mu'}{\mu}$ of the *absolute* indices μ', μ, of the second and first, or their indices of refraction from vacuum.

190. This demonstration, it is true, holds good only for the case when the angles of incidence and refraction at the common surface are both less than the limits of the angles of refraction from vacuum into each medium. If they exceed these limits, the proposition however still holds good, as may be shown by direct measures of the angles of incidence and refraction in any proposed case. At present, therefore, we must receive it as an experimental truth.

191. *Example.* Required the ratio of the sine of incidence to that of refraction out of water into flint glass. The refractive index of flint glass is 1.60, and that of water 1.336, therefore the refractive ratio required is

$$\frac{1.60}{1.336} = 1.197.$$

192. If the index $\mu = -1$, the general law of refraction coincides with that of reflexion. Thus all the cases of reflexion, as far as the direction of the reflected ray is concerned, are included in those of refraction.

Of the Ordinary Refraction of Light through a System of Plane Surfaces, and of Refraction through Prisms.

193. *Definition.* In Optics, any medium having two plane surfaces, through which light may be transmitted, inclined to each other at any angle, is called a *prism.*

194. *Definition.* The *edge* of the prism is the line, real or imaginary, in which the two plane surfaces meet, or would meet if produced.

195. *Definition.* The *refracting angle* of the prism is the angle on which its two plane surfaces are inclined to each other.

196. *Definition.* The *faces* of a prism are the two plane surfaces.

197. *Definition.* The plane perpendicular to both surfaces, and therefore to the edge of a prism, is called the principal section of the prism, or of the two surfaces. This expression has been used in this general sense already, under the head of reflexion.

To determine the direction of a Ray after Refraction through any System of Plane Surfaces.

198. General problem of the refraction through any system of plane surfaces. Fig. 27.

Construction. Since the direction of the ray is the same whether refracted at the given surfaces, or at others parallel to them, conceive surfaces parallel to the given ones, all passing through one point, and from this point, but wholly exterior to the refracting media, let perpendiculars C P, C P′, C P″, &c. be drawn to each of the surfaces, (fig. 27.) Let S C be the direction of the incident ray. Between C P and C S′ draw C S′ in the plane S C P, so that $\sin PCS' = \frac{1}{\mu} . \sin PCS$, μ being the index of refraction of the first medium from the medium in which the ray originally moved, which we will at present suppose a vacuum, then will S′C be the direction of the ray after the first refraction. Again, let μ' = the relative refractive index of the second medium *out of the first*, or $\mu\mu'$ = its absolute refractive index from a vacuum; draw C S″ in the plane S′C P′ so as to make $\sin P'CS'' = \frac{1}{\mu'} . \sin P'CS'$, then will S″C be the direction of the ray after the second refraction, and so on.

199. *General analysis.* Let a = S C P the first angle of incidence, a' = S′C P′ the angle of incidence on the second surface, I = P C P′ the inclination of the two first surfaces to each other, and putting, moreover,

θ = P S′P′ = the angle which the planes of the first and second refraction make with each other.

ψ = S P P′ = the angle made by the plane of the first refraction with the principal section of the two first refracting surfaces.

ϕ = S′P′P = the angle made by the plane of the second refraction with the same principal section.

ρ = P C S′ the first, and ρ' = P′C S″ the second angle of refraction.

D = S C S″ the deviation after the second refraction.

because $$\cos \mathrm{I} = 1 - 2\left(\sin \frac{\mathrm{I}}{2}\right)^2 \text{ and } \sin \mathrm{I} = 2 . \sin \frac{\mathrm{I}}{2} . \cos \frac{\mathrm{I}}{2}.$$

Now $\mu \sin \rho = \sin \alpha$ by the first of the equations (*c*), hence we get (equation *d*)

$$\sin (\mathrm{I} + \mathrm{D} + \alpha) = \sin \alpha + 2\mu . \sin \frac{\mathrm{I}}{2} . \cos \left(\frac{\mathrm{I}}{2} + \rho\right); \qquad (d)$$

whence, I and α being given, and ρ calculated from the equation $\sin \rho = \frac{1}{\mu} \sin \alpha$, D is easily had.

205. *Corol.* 2. If $\alpha = o$, or if the ray be intromitted perpendicularly into the first surface, we have also $\rho = o$, and the expression (*d*) becomes simply

$$\sin (\mathrm{I} + \mathrm{D}) = \mu . \sin \mathrm{I}, \qquad (e)$$

whence also $$\mu = \frac{\sin (\mathrm{I} + \mathrm{D})}{\sin \mathrm{I}}; \qquad (f)$$

Thus we see that if $\mu . \sin \mathrm{I} > 1$, or if I, the angle of the prism, be greater than $\sin^{-1} \frac{1}{\mu}$,* the critical angle, or the least angle of total internal reflexion, the deviation becomes imaginary, and the ray cannot be transmitted at such an incidence.

206. 1st mode of determining the index of refraction by experiment. *Corol.* 3. The equation (*f*) affords a direct method of determining by experiment the refractive index of any medium which can be formed into a prism. We have only to measure the angle of the prism, and the deviation of a ray intromitted perpendicularly to one of its faces. Thus I and D being given by observation, μ is known. This is not, however, the most convenient way; a better will soon appear.

207. *Definitions.* One medium in Optics is said to be *denser* or *rarer* than another, according as a ray in passing from the former into the latter is bent *towards* or *from* the perpendicular. When we speak of the *refractive density* of a medium, we mean that quality by which it turns the ray more or less from its course towards the perpendicular (from a vacuum,) and whose numerical measure is the quantity μ the index of refraction.

208. Limit of the refracting angle of a prism. *Proposition.* Given the index of refraction of a prism, to find the limit of its refracting angle, or that which if exceeded, no ray can be directly transmitted through both its faces.

This limit is evidently that value of I which just renders the angle of refraction ρ' imaginary for all angles of incidence on the first surface, or for all values of α, that is, which renders in all cases

$$\mu . \sin \{ \mathrm{I} + \rho \} - 1 \text{ positive,}$$

or, $\sin (\mathrm{I} + \rho) - \frac{1}{\mu}$ positive; that is, (since $\mathrm{I} + \rho$ cannot exceed 90°) which renders in all cases $\mathrm{I} + \rho - \sin^{-1}\left(\frac{1}{\mu}\right)$ positive. Now $\rho = \sin^{-1} \frac{\sin \alpha}{\mu}$, and consequently the value of α least favourable to a positive value of the function under consideration is $-90°$, which makes $\rho = -\sin^{-1}\left(\frac{1}{\mu}\right)$, its greatest negative value. Consequently, in order that no second refraction shall take place, I must at least be such that $\mathrm{I} - 2 \sin^{-1}\left(\frac{1}{\mu}\right)$ shall be positive; that is, I, the angle of inclination of the faces of the prism to each other, or as it is briefly expressed, the *angle of the prism*, must be at least twice the maximum angle of internal incidence.

Angle of a prism.

209. For example, if $\mu = 2$, I must be at least 60°. In this case no ray can be transmitted *directly* through an equilateral prism of the medium in question.

210. *Corol.* 4. If $\mu > 1$, or if the prism be denser than the surrounding medium, $\mu . \sin \mathrm{I}$ is $> \sin \mathrm{I}$ and $\sin^{-1} (\mu . \sin \mathrm{I}) > \mathrm{I}$, so that the value of D (equation (*d*), Art. 204) is positive, or the ray is bent towards the thicker part of the prism, (see fig. 29.) If $\mu < 1$, or the prism be rarer than the medium, the contrary is the case, (see fig. 30.)

211. Case of minimum deviation. *Problem.* The same case being supposed, (that of a prism in vacuo, or in a medium of equal density on both sides,) required to find in what direction a ray must be incident on its first surface so as to undergo the least possible deviation.

Since $\mathrm{D} = \rho' - \alpha - \mathrm{I}$; (*c*) Art. 203, and by the condition of the minimum, $d\,\mathrm{D} = o$, we must have

$$d\rho' = d\alpha.$$

Now the equations (*c*) give by differentiation

$$d\alpha . \cos \alpha = \mu\, d\rho . \cos \rho; \quad d\alpha' = d\rho; \quad d\rho' . \cos \rho' = \mu\, d\alpha . \cos \alpha',$$

that is $$d\rho' . \cos \rho' = \mu\, d\rho . \cos \alpha' = d\alpha . \frac{\cos \alpha . \cos \alpha'}{\cos \rho},$$

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* The reader will observe, that by the expression $\sin^{-1} \frac{1}{\mu}$ is meant what in most books would be expressed by arc sin $= \frac{1}{\mu}$.

Part I.

or
$$\frac{d\rho}{d\alpha}\,(=1) = \frac{\cos\alpha\,.\,\cos\alpha'}{\cos\rho\,.\,\cos\rho'}\,;\ \text{or}\ \cos\alpha\,.\,\cos\alpha' = \cos\rho\,.\,\cos\rho'.$$

That is, squaring,
$$(1-\sin\alpha^2)\,(1-\sin\alpha'^2) = (1-\sin\rho^2)\,(1-\sin\rho'^2)$$
in which, for $\sin\alpha$ and $\sin\rho'$ writing their equals, $\mu'\,.\,\sin\rho$ and $\mu\,.\,\sin\alpha'$, we get
$$\frac{1-\mu^2\,.\,\sin\rho^2}{1-\sin\rho^2} = \frac{1-\mu^2\,.\,\sin\alpha'^2}{1-\sin\alpha'^2},$$
which gives, on reduction, simply $\sin\rho^2 = \sin\alpha'^2$, and therefore $\rho = \pm\,\alpha'$, that is $I+\rho = I\pm\alpha'$, or $\alpha' = I\pm\alpha'$. The upper sign is unsatisfactory, as it would give $I=0$. The lower therefore must be taken, which gives $\alpha' = \frac{I}{2}$, which satisfies the conditions of the question. We therefore have
$$\alpha' = \tfrac{1}{2}I\,;\ \rho = -\tfrac{1}{2}I\,;\ \sin\alpha = -\,\mu\,.\,\sin\left(\frac{I}{2}\right);\ \sin\rho' = +\,\mu\,.\,\sin\left(\frac{I}{2}\right).$$

This state of things is represented in fig. 31, for the case where $\mu > 1$, or where the prism is denser than the surrounding medium, and in fig. 32, for that in which it is rarer, or $\mu < 1$. In both cases, α, being negative, indicates that the incident ray must fall on the side of the perpendicular C P, *from* the edge A of the prism (as S C). In both cases, the equations $\rho\ (= \mathrm{P\,C\,S'}) = -\tfrac{1}{2}I\ (= -\tfrac{1}{2}\,\mathrm{P\,C\,P'})$ and $\alpha' = \mathrm{P'\,C\,S'} = +\tfrac{1}{2}\,\mathrm{P\,C\,P'}$, indicate that the once refracted ray S′ C D bisects the angle P C P′, and therefore that the portion of it C D within the prism makes equal angles with both its faces. In both cases, also, the equality of the angles α and ρ' (without reference to their signs) shows that the incident and emergent rays make equal angles with the faces of the prism, and therefore that it is of no consequence on which face the ray is first received. Fig. 31. Fig. 32.

Corol. 5. In this case, also, we have the actual amount of the deviation 212. Expression for the minimum deviation.
$$D = \rho' - \alpha - I = 2\sin^{-1}\left(\mu\,.\,\sin\frac{I}{2}\right) - I. \qquad (f)$$
Hence also
$$\sin\frac{I+D}{2} = \mu\,.\,\sin\frac{I}{2}.$$

Corol. 6. In the same case, I being given by direct measurement, and D by observation, of the actual minimum deviation of a ray refracted through any prism, the value of μ, its index of refraction, is given at once, for we have 213. Another mode of determining the index of refraction of a prism by experiment.
$$\mu = \frac{\sin\left(\frac{I+D}{2}\right)}{\sin\left(\frac{I}{2}\right)}. \qquad (g)$$
And this affords the easiest and most exact means of ascertaining the refractive index of any substance capable of being formed into a prism.

Example. A prism of silicate of lead, consisting of silica and oxide of lead, atom to atom, had its refracting angle 21° 12′. It produced a deviation of 24° 46′ *at the minimum* in a ray of homogeneous extreme red light: what was the refractive index for that ray? 214. Example.

$$I = 21^\circ\,12',\ \frac{I}{2} = 10^\circ\,36',\ D = 24^\circ\,46',\ \frac{D}{2} = 12^\circ\,23'$$
$$\sin\left(\frac{I}{2}+\frac{D}{2}\right) = \sin 22^\circ\,59' \qquad 9.59158$$
$$\sin\frac{I}{2} \qquad\qquad = \sin 10^\circ\,36' \qquad 9.26470$$
$$\mu = 2.123 \qquad \overline{0.32688}$$

Case 3. Let us now take a somewhat more general case, viz. to find the final direction and total deviation of a ray, after any number of refractions at plane surfaces, all the refractions being performed in one plane, and, of course, all the common sections of the surfaces being supposed parallel. 215.

Supposing (as above) I to represent the inclination of the first surface to the second; I′ that of the to the third, &c.; and I, I′, &c. to be negative when the surfaces incline the contrary way from one side assumed as positive, taking also $\delta, \delta', \delta''$, &c. . . . . . $\delta^{(n-1)}$ to represent the several partial bendings at the first, second, third, *n*th surface respectively, and the other symbols remaining as before, total deviation, $D = \delta + \delta' + \ldots.\ \delta^{(n-1)}$. Now we have, since in each case $\theta = 180^\circ$,

$$\sin a = \mu \,.\, \sin \rho\,; \quad a' = \rho + \mathrm{I}\,; \quad \mu' \,.\, \sin \rho' = \sin a'\,; \quad \delta = a - \rho\,;$$

$$\sin a' = \mu' \,.\, \sin \rho'\,; \quad a'' = \rho' + \mathrm{I}'\,; \quad \mu'' \,.\, \sin \rho'' = \sin a''\,; \quad \delta' = a - \rho'\,; \ \text{\&c. \&c.}$$

Hence we get (supposing n to represent the number of surfaces)

$$\sin \rho = \frac{1}{\mu} \,.\, \sin a$$

$$\sin \rho' = \frac{1}{\mu'} \,.\, \sin (\mathrm{I} + \rho)$$

$$\sin \rho'' = \frac{1}{\mu''} \,.\, \sin (\mathrm{I}' + \rho')$$

— — — — — — —

$$\sin \rho^{(n-1)} = \frac{1}{\mu^{(n-1)}} \,.\, \sin (\mathrm{I}^{(n-2)} + \rho^{(n-2)})$$

whence the series of values ρ, ρ', &c. may be continued to the end. These determined, we get a, a', &c. by the equations $\quad a = a\,; \quad a' = \rho + \mathrm{I}\,; \quad a'' = \rho' + \mathrm{I}'\,; \ \ldots . a^{(n-1)} = \rho^{(n-2)} + \mathrm{I}^{(n-2)}$,

and finally

$$\begin{aligned} \mathrm{D} &= \{ a + a' + \ldots . a^{(n-1)} \} - \{ \rho + \rho' + \ldots . \rho^{(n-1)} \} \\ &= a + \{ \mathrm{I} + \mathrm{I}' + \ldots . \mathrm{I}^{(n-2)} \} - \rho^{(n-1)}. \end{aligned}$$

Now $\mathrm{I} + \mathrm{I}' + \ldots \mathrm{I}^{(n-2)}$ is the inclination of the first to the last surface, or the angle (A) of the compound prism, formed of the assemblage of them all, so that we have in general

$$\mathrm{D} = a + \mathrm{A} - \rho^{(n-1)} \qquad (h)$$

216. Case of minimum deviation after any number of refractions.

Let us now inquire, how a ray must be incident on such a system of surfaces so that its total deviation shall be a minimum.

Since $d\,\mathrm{D} = o$ and I, I′, &c. are constant, we must have

$$d\,a = d\,\rho^{(n-1)},$$

but

$$\left.\begin{aligned} \mu \,.\, \sin \rho &= \sin a \\ \mu' \,.\, \sin \rho &= \sin (\rho + \mathrm{I}) \\ &\text{\&c.} \end{aligned}\right\} \therefore \left\{\begin{aligned} &\mu\, d\rho \,.\, \cos \rho = d\,a \,.\, \cos a \\ &\mu'\, d\rho' . \cos \rho' = d\,\rho \,.\, \cos (\rho + \mathrm{I}) \\ &\overline{} \quad \overline{} \quad \overline{} \quad \overline{} \\ &\mu^{(n-1)} d\,\rho^{(n-1)} . \cos \rho^{(n-1)} = d\,\rho^{(n-2)} . \cos (\rho^{(n-2)} + \mathrm{I}^{(n-2)}) \end{aligned}\right.$$

and multiplying all these equations together

$$\mu \mu \ldots . \mu^{(n-1)} . \cos . \rho \cos \rho' \ldots . \cos \rho^{(n-1)} . \frac{d\,\rho^{(n-1)}}{d\,a} = \cos a \,.\, \cos (\rho + \mathrm{I}) \ldots . \cos (\rho^{(n-2)} + \mathrm{I}^{(n-2)})$$

or simply

$$\mu \mu' \ldots . \mu^{(n-1)} . \cos \rho \,.\, \cos \rho' \ldots . \cos \rho^{(n-1)} = \cos a \,.\, \cos a' \ldots .. \cos a^{(n-1)}; \qquad (i)$$

this equation, combined with the relations already stated, between the successive values of ρ and those of a, afford a solution of the problem; but the final equations to which it leads are of great complexity and high dimensions. Thus, in the case of only three refractions, the final equation in sin ρ or sin ρ', &c. rises to the sixteenth degree; and though its form is only that of an equation of the eighth, yet there appears no obvious substitution by which it can be brought lower. The only case where it assumes a tractable form is that of two surfaces, when the equation (i) which in general may be put under the form

$$\mu^2 \mu'^2 \ldots . \mu^{(n)2} (1 - \sin \varrho^2)\, (1 - \sin \varrho'^2), \text{\&c.} = (1 - \mu^2 . \sin \rho^2)\, (1 - \mu' \ \ . \sin \rho'^2), \text{\&c.} \qquad (j)$$

reduces itself by putting $\quad \sin \varrho^2 = x, \ \text{and} \sin \rho'^2 = y,$

to

$$(\mu^2 \mu'^2 - 1) - \mu^2 (\mu'^2 - 1)\, x - \mu'^2 (\mu^2 - 1)\, y = 0,$$

which, combined with the equation $\quad \mu' . \sin \rho' = \sin (\varrho + \mathrm{I})$

or

$$(\mu'^2 y + x - \sin \mathrm{I}^2)^2 = 4\, \mu'^2 . \cos \mathrm{I}^2 \,.\, x\, y,$$

gives a final equation of a quadratic form for determining x or y, and which in the particular case of $\mu \mu =$ or when the second refraction is made into the same medium in which the ray originally moved before its fi incidence, gives the same result we have already found for that case by a similar process. Meanwhile, thou we may not be able to resolve the final equations in the general case, the equation (j) affords a criterion of state of minimum deviation which may prove useful in a variety of cases.

217. Case when the planes of the first and second refraction are at right angles.

Case 4. When the planes of the first and second refraction are at right angles to each other, required the relations arising from this condition.

In this case we have $\theta = 90^\circ$, $\cos\theta = 0$, $\sin\theta = 1$, so that the general equation (B, 199) becomes

$$\left.\begin{array}{l}\sin\alpha = \mu \,.\, \sin\rho \\ \sin\alpha' = \mu' \,.\, \sin\rho' \\ \sin\alpha' = \sin I \,.\, \sin\psi\end{array}\right\}\text{and } \cos\alpha' = \cos\varrho \,.\, \cos I + \sin\rho \,.\, \sin I \,.\, \cos\psi.$$

The last of these equations, by transposition and squaring, becomes

$$\cos\alpha'^2 - 2 \,.\, \cos\alpha' \,.\, \cos\rho \,.\, \cos I + \cos\varrho^2 \,.\, \cos I^2 = \sin\rho^2 \,.\, \sin I^2 \, (1 - \sin\psi^2)$$

in which, substituting for $\sin\psi$ its value $\dfrac{\sin\alpha'}{\sin I}$ deduced from the third equation, and reducing as much as possible, we obtain

$$\cos\alpha'^2 \,.\, \cos\rho^2 - 2 \,.\, \cos\alpha' \,.\, \cos\rho \,.\, \cos I + \cos I^2 = 0,$$

which, being a complete square, gives simply

$$\cos\rho \,.\, \cos\alpha' = \cos I. \qquad (k)$$

This answers to the equation $\cos\alpha \,.\, \cos\alpha' = \cos I$, obtained, on the same hypothesis, in the case of reflexion (104); for since the latter case is included in the case of refraction, by putting $\mu = -1$ (Art. 192) we have then $\alpha = -\rho$ and $\cos\rho = \cos\alpha$.

Corol. 1. If i and i' be the inclinations to the first and second surfaces respectively of that part of the ray which lies between the surfaces, we have 218.

$$i = 90^\circ - \varrho \qquad \text{and } i' = 90^\circ - \alpha',$$

so that the equation above found, gives

$$\sin i \,.\, \sin i' = \cos I,$$

or the product of the sines of the inclination of the ray between the surfaces to either surface is equal to the cosine of the inclination of the two surfaces. The same relation may be expressed otherwise, thus: if we suppose the ray to pass both ways from within, out of the prism, the product of the cosines of its interior incidences on the two surfaces is equal to the cosine of their inclination to each other. In this way of stating it, the case of reflexion is included.

Corol. 2. We have also in the present case 219

$$\sin\rho = \frac{1}{\mu} \,.\, \sin\alpha\,; \qquad \sin\alpha' = \sqrt{\frac{\mu^2 \,.\, \sin I^2 - \sin\alpha^2}{\mu^2 - \sin\alpha^2}}\,; \qquad \sin\rho' = \frac{1}{\mu'}\sqrt{\frac{\mu^2 \,.\, \sin I^2 - \sin\alpha^2}{\mu^2 - \sin\alpha^2}}$$

and

$$\cos D = \cos(\alpha - \varrho) \,.\, \cos(\alpha' - \rho')$$

so that α being given, all the rest become known. The last equation corresponds to the equation $\cos D = \cos 2\alpha \,.\, \cos 2\alpha'$ in the case of reflexion.

§ VII. *Of Ordinary Refraction at Curved Surfaces, and of Diacausties, or Caustics by Refraction.*

220. The refraction at a curved surface being the same as at a plane, a tangent at the point of incidence, if we know the nature of the surface, we may investigate, by the rules of refraction at plane surfaces, combined with the relations expressed by the equation of the surface, in all cases, the course of the refracted ray. We shall confine ourselves to the simple case of a surface of revolution, having the radiant point in the axis.

221. General investigation of the focus of any curve surface of revolution. Fig. 33.

Proposition. Given a radiant point in the axis of any refracting surface of revolution, required the focus of any annulus of the surface.

Let C P be the curve, Q the radiant point, Q q N the axis, P M any ordinate, P N a normal, and P q or q P the direction of the refracted ray, and therefore q the focus of the annulus described by the revolution of P. Then if we put μ for the refractive index, and, assuming Q for the origin of the coordinates, put $QM = x$, $MP = y$, $r = \sqrt{x^2 + y^2}$, $p = \dfrac{dy}{dx}$, we have

$$\sin QPM = \frac{x}{r}\,; \qquad \cos QPM = \frac{y}{r}\,;$$

$$\sin \mathrm{NPM} = \frac{p}{\sqrt{1+p^2}}; \qquad \cos \mathrm{NPM} = \frac{1}{\sqrt{1+p^2}}$$

consequently $$\sin \mathrm{NPQ} = \sin \mathrm{QPM} . \cos \mathrm{NPM} + \sin \mathrm{NPM} . \cos \mathrm{QPM}$$

$$= \frac{x + py}{r . \sqrt{1+p^2}},$$

and therefore $$\sin \mathrm{NP}q = \frac{1}{\mu} . \sin \mathrm{NPQ} = \frac{x + py}{\mu r \sqrt{1+p^2}};$$

and $$\cos \mathrm{NP}q = \frac{Z}{\mu r \sqrt{1+p^2}}, \text{ if we put } Z = \sqrt{\mu^2 r^2 (1+p^2) - (x+py)^2}; \qquad (a)$$

consequently since $\mathrm{MP}q = \mathrm{NP}q + \mathrm{NPM}$, we get

$$\sin \mathrm{MP}q = \frac{x + py + pZ}{\mu r (1+p^2)}; \qquad \text{and } \cos \mathrm{MP}q = \frac{-p(x+py) + Z}{\mu r (1+p^2)};$$

whence $$\tan \mathrm{MP}q = \frac{\sin \mathrm{MP}q}{\cos \mathrm{MP}q} = \frac{x + py + pZ}{-p(x+py) + Z}.$$

Now we have $$\mathrm{M}q = \mathrm{PM} . \tan \mathrm{MP}q = y . \tan \mathrm{MP}q = \frac{y(pZ + (x+py))}{Z - p(x+py)}; \qquad (b)$$

consequently $$\mathrm{Q}q = x + y . \tan \mathrm{MP}q = (x+py) . \frac{px - y - Z}{p(x+py) - Z}. \qquad (c)$$

222. *Corol.* 1. If we put s for the arc C P of the curve, we have, since $r\,dr = x\,dx + y\,dy = dx(x + py)$,

$$Z = \sqrt{\mu^2 r^2 . \left(\frac{ds}{dx}\right)^2 - \left(\frac{r\,dr}{dx}\right)^2} = r . \sqrt{\mu^2 \left(\frac{ds}{dx}\right)^2 - \left(\frac{dr}{dx}\right)^2}; \qquad (d)$$

223. *Corol.* 2. If $\mu = -1$, in which case the refraction becomes a reflexion, we have $Z = \sqrt{r^2 (1+p^2) - (x+py)^2} = y - px$, writing for r^2 its value $x^2 + y^2$; so that the general value above found for $\mathrm{Q}q$ reduces itself to

$$\mathrm{Q}q = 2 . \frac{(x+py)(px-y)}{2px - y(1-p^2)},$$

which is the same as that found in (*b*) Art. 109, in the case of reflexion.

224. *Corol.* 3. If we put $\mathrm{P} = \tan \mathrm{M}q\mathrm{P} = \operatorname{cotan} \mathrm{MP}q = \frac{1}{\tan \mathrm{MP}q}$,

we have $$\mathrm{P} = \frac{-p(x+py) + Z}{x + py + pZ}, \qquad (e)$$

and the equation of the refracted ray, if X and Y be its coordinates, (Q being their origin) will be (since Y lies on the opposite side of the curve from Q)

$$\mathrm{Y} - y = -\mathrm{P} . (\mathrm{X} - x) \qquad (f)$$

225 In the case of parallel rays these expressions become (by putting first $x + a$ for x, and then making a infinite)

$$\left.\begin{array}{l} Z = a \sqrt{\mu^2 (1+p^2) - 1} \\ \mathrm{P} = \dfrac{-p + \sqrt{\mu^2(1+p^2) - 1}}{1 + p\sqrt{\mu^2(1+p^2) - 1}} \end{array}\right\}; \qquad (g)$$

$$\mathrm{A}q = x + y . \frac{1 + p\sqrt{\mu^2(1+p^2) - 1}}{\sqrt{\mu^2(1+p^2) - 1} - p}. \qquad (h)$$

Squaring both sides, and substituting for Z its value, we get

$$(x + py)^2 \{ (p(x - c) - y)^2 + (x - c + py)^2 \} = (x - c + py)^2 . \mu^2 (x^2 + y^2)(1 + p^2)$$

which, on executing the operations indicated on the left hand side, becomes totally divisible by $1 + p^2$, and reduces itself to

$$(x + py)^2 (y^2 + (x - c)^2) = \mu^2 (x - c + py)^2 (y^2 + x^2)$$

that is, putting for p its value $\frac{dy}{dx}$, multiplying by dx^2, and extracting the square root,

$$\frac{x\,dx + y\,dy}{\sqrt{x^2 + y^2}} = \mu . \frac{(x - c)\,dx + y\,dy}{\sqrt{(x - c)^2 + y^2}},$$

and integrating (each side being a complete differential)

$$\sqrt{x^2 + y^2} = b + \mu . \sqrt{(x - c)^2 + y^2}, \qquad (n)$$

which is the equation of the curve required, and belongs, generally, to a curve of the fourth order.

233. *Corol.* 1. About Q, (fig. 36,) with any radius Q A, arbitrarily assumed, describe a circle A B D E, then if C P
Fig. 36. be the refracting curve, and we put $QA = b$, we have $QP = \sqrt{x^2 + y^2}$, $Pq = \sqrt{(x - c)^2 + y^2}$, and the nature of the curve is expressed by the property

$$BP = \mu . Pq, \qquad \text{or, } BP : Pq :: \mu : 1.$$

234. *Corol.* 2. If $b = o$, or the circle A B E be infinitely small, we have $QP : Pq :: \mu : 1$, which is a well known property of the circle. In fact, in this case we have simply

$$x^2 + y^2 = \mu^2 \{ (x - c)^2 + y^2 \}$$

In this, if we change the origin of the coordinates by writing $x + \frac{\mu^2}{\mu^2 - 1} c$ for x, we find

$$y^2 = \left(\frac{\mu}{\mu^2 - 1} c\right)^2 - x^2.$$

The radius of the circle, therefore, is equal to $\frac{\mu}{\mu^2 - 1} \times Qq$, and the distance of its centre from the radiant
Fig. 37. point is $\frac{\mu^2}{\mu^2 - 1} \times Qq$. Take therefore any circle H P C whose centre is E, (fig. 37,) and two points Q, q, such that $QE = \mu \times EC$ and $QC : Cq :: \mu : 1$. Then if rays diverge from Q, and fall on the surface P H beyond the centre, they will, after refraction into the medium M, all diverge from q.

235. *Corol.* 3. If $\mu = -1$, the equation (n), when freed from radicals, is only of the second degree between x and y, and therefore belongs to a conic section. On executing the reduction we get

$$y^2 = \left(1 - \frac{c^2}{b^2}\right) \left(\left(\frac{b}{2}\right)^2 = \left(x - \frac{c}{2}\right)^2\right),$$

which shows that the radiant point Q is in one focus and q in the other, which is the same result as that before found by a different mode of integration.

236. *Corol.* 4. When Q is infinitely distant, and the rays are parallel, we must shift the origin of the coordinates
For parallel rays the curve is a conic section. from Q to q, by putting $c - x$ for x, and *afterwards* supposing c infinite. This gives

$$\sqrt{c^2 - 2cx + x^2 + y^2} = b + \mu \sqrt{x^2 + y^2}.$$

Fig. 38. Developing the first term in a descending series, we find

$$(c - b) - x + \frac{x^2 + y^2}{2c^2} + \&c. = \mu . \sqrt{x^2 + y^2}.$$

Let $c - b = h$, which, since b is arbitrary, is equally general, and may represent any finite quantity, then, as c increases and at length becomes infinite, this equation becomes ultimately

$$h - x = \mu \sqrt{x^2 + y^2}.$$

Let C P be a conic section, q its focus, and A B its directrix, $qM = x$, and $PM = y$, then will $QP = h - x$ if we take $qA = h$, and the above equation we see expresses that well known property of a conic section, in virtue of which $QP : Pq$ in a constant ratio, ($\mu : 1$.)

237. *Corol.* 5. The curve is an ellipse when $QP \; 7 \; Pq$, or when the ray is incident from a rarer on a denser medium, and an hyperbola in the contrary case. If $QP = Pq$, the curve is a parabola; in this case $\mu = 1$, and the rays converge to the focus at an infinite distance, *i. e.* remain parallel.

238 To take a single example of the investigation of the diacaustic curve, from the general expressions above

246. Focus for parallel rays

Corol. 2. If we suppose the focus of incident rays infinitely distant, or $a = \infty$, and take F the place of q for central rays, on that supposition, F will be the principal focus, and we shall have

$$\left.\begin{array}{l} \mathrm{CF} = \dfrac{\mu r}{\mu - 1}; \text{ that is, } \mathrm{CE : CF} :: \mu - 1 : \mu \\ \mathrm{CE : EF} :: \mu - 1 : 1, \text{ and } \mathrm{CF : FE} :: \mu : 1 \end{array}\right\}. \qquad (d)$$

whence we also find

247. These results will be expressed more conveniently for our future reference by adopting a different notation. Let, then,

$\mathrm{R} = \dfrac{1}{r}$ = curvature of the surface, and let positive values of r and R correspond to the case where the centre E lies to the right of the vertex C, or in the direction in which the rays proceed.

$\mathrm{D} = \dfrac{1}{\mathrm{QC}}$ (fig. 42) = proximity of the focus of incident rays to the surface, D being regarded as positive when Q lies to the *right* of C, as in fig. 42, and as negative when to the left, as in fig. 41. Then, since $\mathrm{QE} = a$, and since in the foregoing analysis a is regarded as positive when Q is to the *left* of E, we must have (fig. 42) $\mathrm{QE} = -a$, and $\mathrm{QC} = \mathrm{QE} + \mathrm{EC} = r - a$, so that

$\mathrm{D} = \dfrac{1}{r - a}$; $\quad a = \dfrac{1}{\mathrm{R}} - \dfrac{1}{\mathrm{D}}$. Let also $m = \dfrac{1}{\mu}$:

$\mathrm{F} = \dfrac{1}{\mathrm{CF}}$ = power of the surface:

$f = \dfrac{1}{\mathrm{C}q}$ = proximity of the focus of refracted rays to the surface.

Positive values of F and f, as well as of D and R, being supposed to indicate situations of the points F, f, Q, E, respectively, to the right of C, or in the direction towards which the light travels. This is, in fact, assuming for our positive case that of *converging* rays incident on a *convex* surface of a *denser* medium. We shall have, then,

$$r = \frac{1}{\mathrm{R}}; \quad r' - a = \frac{1}{\mathrm{D}}; \quad a = \frac{1}{\mathrm{R}} - \frac{1}{\mathrm{D}}; \quad \mu = \frac{1}{m}.$$

Fundamental equation for the foci of central rays.

But equation (b) gives $\dfrac{1}{\mathrm{C}q} = \dfrac{a + \mu(r - a)}{\mu r (r - a)}$, and substituting we shall get

$$f = (1 - m)\,\mathrm{R} + m\,\mathrm{D}. \qquad (e)$$

This equation comprises the whole doctrine of the foci of spherical surfaces for central rays, and may be regarded as the fundamental equation in their theory.

248. General expression for the power of any surface.

In the case of parallel rays, we have $\mathrm{D} = 0$, whether the rays be incident from left to right, or from right to left. In either case, then, f has the same value, viz. $(1 - m)\,.\,\mathrm{R}$, and the principal focal distance F in either case is the same, being given by the equation

$$\mathrm{F} = (1 - m)\,.\,\mathrm{R}, \qquad (f)$$

which shows, moreover, that the power of any spherical surface is in the direct ratio of its curvature.

249. Hence also we have $\qquad f = \mathrm{F} + m\,\mathrm{D}. \qquad (g)$

250. Fundamental expressions for the central foci in case of reflexion.

In the case of reflexion, where $\mu = -1$, or $m = -1$, these equations become respectively

$$\mathrm{F} = 2\,\mathrm{R}; \quad f = 2\,\mathrm{R} - \mathrm{D}; \quad f = \mathrm{F} - \mathrm{D}. \qquad (h)$$

Such are the expressions for the central foci in the case of a single surface. Let us now consider that of any system of spherical surfaces.

251. Central focus of a system of spherical surfaces investigated. Fig. 43.

Problem. To find the central focus of any system of spherical surfaces.

Let C′, C″, C‴, &c. be the surfaces. Q′ the focus of rays incident on C′, Q″ that of refracted rays, or the focus of rays incident on C″, and so on. Call also R′, R″, &c. the radii of the first, second, &c. surfaces μ', μ'', &c. their refractive indices, or $\dfrac{\text{sin inc}}{\text{sin ref}}$ into each medium from that immediately preceding, $m' = \dfrac{1}{\mu'}$, $m'' = \dfrac{1}{\mu''}$, &c. Also let $\mathrm{D}' = \dfrac{1}{\mathrm{C'Q'}}$, $\mathrm{D}'' = \dfrac{1}{\mathrm{C''Q''}}$, &c. and moreover let $\mathrm{C'C''} = t'$, $\mathrm{C''C'''} = t''$, &c. t', t'', &c. being regarded as positive when C″, C‴, &c. respectively lie to the right of C′, C″, &c. or in the direction in which the light travels; and if we put $\dfrac{1}{\mathrm{C'Q''}} = f'$, $\dfrac{1}{\mathrm{C''Q'''}} = f''$, &c. $\mathrm{F}' = (1 - m')\,\mathrm{R}'$, $\mathrm{F}'' = (1 - m'')\,\mathrm{R}''$, &c. we shall have by (249)

$$f' = \mathrm{F}' + m'\,\mathrm{D}'; \quad f'' = \mathrm{F}'' + m''\,\mathrm{D}'', \text{ \&c.}; \qquad (i)$$

260. Species of lenses how distinguished algebraically.

These different species are distinguished, algebraically, by the equations of the surfaces, and by the signs of their radii of curvature. In the case of spherical lenses, to which our attention will be chiefly confined, if we suppose a positive value of the radius of curvature to correspond to a surface whose convexity is turned towards the *left*, or towards the incident rays, and a negative to that whose convexity is turned to the right, or from them, we shall have the following varieties of denomination:

$$\left.\begin{array}{l}\text{meniscus}\\ \text{concavo-convex}\end{array}\right\}\left\{\begin{array}{l}\text{both radii } +\text{, as fig. 46, 49, } a\text{, or}\\ \text{both radii } -\text{, as fig. 46, 49, } b\text{,}\end{array}\right.$$

$$\text{plano-convex}\left\{\begin{array}{l}\text{radius of first surface } +\text{, of second infinite, fig. 45, } b\text{,}\\ \text{radius of first surface infinite, of second } -\text{, fig. 45, } a\text{,}\end{array}\right.$$

$$\text{plano-concave}\left\{\begin{array}{l}\text{radius of first surface } -\text{, of second } \infty\text{, fig. 48, } b\text{,}\\ \text{radius of first surface } \infty\text{, of second } +\text{, fig. 48, } a\text{,}\end{array}\right.$$

double-convex: radius of first surface +, of second −, fig. 44,

double-concave: radius of first surface —, of second +, fig. 47,

the rays being supposed in all cases to pass from left to right.

A *compound lens* is a lens consisting of several lenses placed close together.

An *aplanatic* lens is one which refracts all the rays incident on it to one and the same focus.

261. Focus of a single lens.

Problem. To find the power and foci of a single thin lens in vacuo.

Let R' and R'' be the curvatures of its first and second surfaces respectively, μ the refractive index of the medium of which it consists, $m = \frac{1}{\mu}$; F its power: then we have, since the last refraction is made into vacuum,

$$F = \mu F' + F''; \qquad f = F + D;$$

but, $F' = (1 - m')R'$, and $F'' = (1 - m'')R''$; and as $\mu' = \frac{1}{\mu}$ and $m'' = \mu$, these become respectively $\frac{1}{\mu}(\mu - 1) R'$ and $-(\mu - 1) R''$, so that the foci of the lens are finally determined by the equations

Fundamental equations.

$$\left.\begin{array}{l}F = (\mu - 1)(R' - R'')\\ f = F + D\end{array}\right\}. \qquad (p)$$

262. Power of a lens.

Corol. 1. The power of a lens is proportional to the difference of the curvatures of the surfaces in a meniscus or concavo-convex lens; and to their sum, in a double-convex or double-concave.

In plano-convex, or plano-concave lenses, the power is simply as the curvature of the convex or concave surface.

263. Fig. 49. Real and virtual foci.

Corol. 2. In double-convex lenses R' is positive and R'' negative, so that when $\mu > 1$, F is positive, or the rays converge to a focus behind the lens. In plano-convex, $R'' = 0$ and R' is +; or $R' = 0$ and R'' is negative, (260); hence in both cases F is positive and the rays also converge. In meniscus lenses also, R' is +, and R'', though +, is less than R', (fig. 49;) therefore in these, also, the same holds good. In all these cases the *focus is said to be real*, because the rays actually meet there. In double-concave, plano-concave, or concavo-concave lenses, the reverse holds good; the focus lies on the opposite side, or towards the incident rays, and parallel rays, after refraction, diverge from it. In this case, therefore, they never meet, and the focus is called a *virtual focus*.

264. *Corol.* 3. If μ be < 1, or the lens be formed of a medium rarer than the ambient medium (which need not be vacuum, provided the whole system be immersed in it,) $\mu - 1$ is negative, and all the above cases are reversed. In this case convex lenses give virtual, and concave, real foci.

265. Positive and negative powers.

Corol. 4. For lenses of denser media, the powers of double-convex, plano-convex, and menisci are positive; and those of double plano-concave and concavo-convex lenses, negative; *vice versâ* for rarer media.

266. *Corol.* 5. The focus of parallel rays is at the same distance, on whichever side of the lens the rays fall. For if the lens be turned above, R' becomes R'', and *vice versâ;* but, since they also change their signs, F remains unaltered.

267. Conjugate foci move in the same direction.

Corol. 6. The equation $f = F + D$ gives $df = dD$. This shows that the foci of incident and refracted rays move always in the same direction, if the former be supposed to shift its place along the axis; and, moreover, that their proximities to the lens vary by equal increments or decrements for each.

268. Central foci of a system of thin lenses in contact.

Problem. To determine the central foci of any system of lenses placed close together, the lenses being supposed infinitely thin.

The general problem of a system of spherical surfaces contains this as a particular case; for we may regard the posterior surface of the first lens, and the anterior of the second, as forming a lens of vacuum interposed between the two lenses, and so for the rest. Thus the system of lenses is resolved into a system of spherical surfaces in contact throughout their whole extent; the alternate media having their refractive indices, or the alternate values of M, unity. If then we call μ', μ'', μ''', &c. the refractive indices of the lenses, we shall have

$$M = 1; \qquad M' = \mu'; \qquad M'' = 1; \qquad M''' = \mu''; \qquad M^{iv} = 1, \text{\&c.}$$

Superposition of powers. Power of a system of lenses is the sum of the powers of the component individuals.

The compound power F then will (258, o) be represented by

$$F = \mu' F' + F'' + \mu'' F''' + F^{iv} + \mu''' F^{v} + F^{vi} +, \&c.$$

But

$$F' = (1 - m') R' = \frac{1}{\mu'} (\mu' - 1) R'$$

$$F'' = (1 - m'') R'' = (1 - \mu') R'',$$

because $m' = \frac{1}{\mu'}$ and $m'' = \mu'$. Consequently,

$$\mu' F' + F'' = (\mu' - 1) (R' - R'')$$

and similarly

$$\mu'' F''' + F^{iv} = (\mu'' - 1) (R''' - R^{iv}), \&c.$$

so that we get, finally,

$$F = (\mu' - 1) (R' - R'') + (\mu'' - 1) (R''' - R^{iv}) + \&c.$$

Now, the several terms of which this consists are (by Art. 261) the respective powers of the individual lenses of which the system consists, so that if we put (according to the same principle of notation) L', L'', L''', &c. for the powers of the single lenses, and L for their joint power as a system, we have

$$L = L' + L'' + L''' +, \&c. \qquad (q)$$

an equation which shows that the *power of any system of lenses is the sum of the powers of the individual lenses which compose it;* the word sum being taken in its algebraic sense, when any of the lenses has a negative power. Moreover it is easy to see that we also have $f = L + D$, as in the case of a single lens.

269 Reciprocally, we may regard a system of spherical surfaces forming the boundaries of contiguous media (as in the instance of a hollow lens of glass enclosing water) as consisting of distinct lenses, by imagining the concavity of one medium and the convexity of that in immediate contact with it separated by an infinitely thin film of vacuum, or of any medium having its surfaces equicurve, as in fig. 50; and thus a system of any number (n) of media, whose surfaces are in contact throughout their whole extent, may be conceived replaced by an equivalent system of $2\,n - 1$ lenses, the alternate ones being vacuum, or void of power. This way of considering the subject has often its use. It, moreover, leads to the result, that *the power of any system of spherical surfaces placed in vacuo is the sum of the powers of the several lenses into which it can be resolved, each placed in vacuo and acting alone.*

Fig. 50.

Power of a system of spherical surfaces expressed.

270. Foci of a system of surfaces separated by small finite intervals.

Let us now return to the case of surfaces separated by finite intervals; and, first, let us inquire the foci of a system of surfaces separated by intervals so small that their squares may be neglected. In this case the equations (j), Art. 251, become simply

$$D' = D; \qquad D'' = f' + f'^2 t'; \qquad D''' = f'' + f''^2 t'', \&c.;$$

and substituting these values in the equations (i), and retaining the notation of Art. 257, we find

$$\left.\begin{aligned} M f = M^{(n)} f^{(n)} = M' F' + M'' F'' + \ldots . \; M^{(n)} F^{(n)} + D \\ + M' f'^2 t' + M'' f''^2 t'' + \ldots . \; M^{(n-1)} f^{(n-1)2} t^{(n-1)} \end{aligned}\right\}.$$

Now in this we are to consider that

$$f' = F' + m' D, \; f'' = F'' + m'' F' + m' m'' D', \&c.$$

and the values of f', f'', &c. so expressed, being substituted in the foregoing equation, we find

$$M f = M' F' + M'' F'' + M''' F''' + \&c. \ldots + D \qquad (r)$$

$$+ M' (F' + m' D)^2 t' + M'' (F'' + m'' F' + m'' m' D)^2 t'' +, \&c.$$

271. Case of a single lens of small but finite thickness.

Corol. In the case of two surfaces, supposing $M = 1$, or in the case of a single lens in vacuo, this gives

$$f = (\mu - 1) (R' - R'') + D + \frac{1}{\mu} \{ (\mu - 1) R' + D \}^2 t. \qquad (s)$$

For parallel rays, this becomes

$$F = (\mu - 1) (R' - R'') + \frac{(\mu - 1)^2}{\mu} R'^2 . \, t; \qquad (t)$$

t being here put for t', the interval between the surfaces or *total thickness* of the lens.

272. Focus of a lens of any thickness.

Problem. To determine the foci of a lens, whose thickness t *is too considerable to allow of any of its powers being neglected.*

Here we must take the strict formulæ

$$D' = D; \qquad D'' = \frac{f}{1 - f' t}; \qquad f' = (1 - m') R' + m' D; \qquad \text{and } f'' = {}'1 - m'') R'' + m'' D''$$

The latter equation gives, on substitution, and recollecting that $m' = \frac{1}{\mu} = m$ and $m'' = \mu$,

$$f = f'' = \frac{(\mu - 1)(R' - R'') + D + \frac{\mu - 1}{\mu}\{(\mu - 1)R' + D\}R'' t}{1 - \frac{1}{\mu}\{(\mu - 1)R' + D\}t}; \qquad (u)$$

and for parallel rays

$$F = \frac{\mu(\mu - 1)(R' - R'') + (\mu - 1)^2 . R' R'' t}{\mu - t . (\mu - 1) R'} \qquad (v)$$

273. Foci of a sphere. *Example* 1. *To determine the foci of a sphere.*

Here $R'' = -R' = -R$; $t = \frac{2}{R}$; and the equations (u) and (v) become

$$f = \frac{(2\mu - 2)R + (2 - \mu)D}{(2 - \mu)R - 2D} R; \qquad F = \frac{2\mu - 2}{2 - \mu} . R. \qquad (w)$$

274. *Corol.* 1. If $\mu = 2$, for instance, these values become

$$f = \frac{R^2}{D}; \qquad F = \infty.$$

In this case, then, since f and F express the proximities of the foci to the posterior surface of the sphere, we see that the focus for parallel rays falls on this surface, and that in any other case (as in fig. 51 and 52) q is given by the proportion

$$QC : CE :: EH : Hq.$$

275. *Corol.* 2. Whatever be the value of μ, the focus for parallel rays after the second refraction bisects the distance between the posterior surface of the sphere, and the focus after the first refraction.

276. Foci of a hemisphere. *Example* 2. To determine the foci of a hemisphere, in the two cases; first, when the convex, secondly, when the plane surface receives the incident light.

In the first case, $R' = R$; $R'' = 0$; $t = \frac{1}{R}$: therefore we find

$$f = \frac{(\mu - 1)R + D}{R - D} . R; \qquad F = (\mu - 1)R.$$

277. In the other case, when the rays fall first on the plane side, $R' = 0$, $R'' = -R$, and $t = \frac{1}{R}$, so that

$$f = \frac{\mu(\mu - 1)R + D}{\mu R - D} R; \qquad F = (\mu - 1)R.$$

278. If the thickness of a spherical segment exposed with its convex side to the incident rays be to the radius μ to $\mu - 1$, or if $t = \frac{\mu}{\mu - 1} . \frac{1}{R} = \frac{1}{(1 - m)R}$, and $R'' = 0$, the expressions (u) and (v) become

$$f = -(\mu - 1) . \frac{R}{D}\{(\mu - 1)R + D\}: \qquad F = \infty$$

In this case the focus for parallel rays falls on the posterior surface of the segment.

279. Focus of any spherical segment, convex side first. In general, for any spherical segment, if exposed with its convex side to the rays, $R'' = 0$, and

$$f = \mu . \frac{(\mu - 1)R + D}{\mu + \{(\mu - 1)R + D\}t}; \qquad F = \frac{\mu(\mu - 1)R}{\mu + (\mu - 1)Rt}.$$

Plane side first. If the plane side be exposed to the rays

$$f = (\mu - 1)R + \frac{\mu D}{\mu - t . D}; \qquad F = (\mu - 1)R.$$

280. Focus of a spherical shell of equal curvatures. If $R' = R''$, or if the lens be a spherical lamina of equal curvatures, the one convex, the other concave,

$$f = \frac{\mu D + (\mu - 1)\{(\mu - 1)R + D\}Rt}{\mu - \{(\mu - 1)R + D\}t}; \qquad F = \frac{(\mu - 1)^2 R^2 t}{\mu - (\mu - 1)Rt}.$$

Light.

286. Case of reflectors.

Case 2. In reflectors, $m = \mu = -1$, and

$$\left.\begin{array}{l} \Delta f = R\,(R-D)^2\,y^2; \qquad \omega = -\dfrac{R\,(R-D)^2}{(2R-D)^2}\,y^2 \\ \text{lateral aberration} = -\tfrac{1}{2}\,(R-D)^2\,y^3 \end{array}\right\}; \qquad (g)$$

which, for parallel rays, become

$$\Delta f = R^3\,y^2; \qquad \omega = -\tfrac{1}{4}\,R\,y^2; \qquad \text{lateral aberration} = -\tfrac{1}{2}\,R^2\,y^2. \qquad (h)$$

287. Aplanatic foci defined and investigated.

In the general case, if we put either $D = R$, or

$$m\,R - (1+m)\,D = o, \text{ which gives } D = \frac{m}{m+1}\,R; \qquad \frac{1}{D} = (\mu+1)\,.\,\frac{1}{R},$$

the value of Δf, and therefore of the aberration, vanishes. The former case is that of rays converging to the centre of curvature, in which, of course, they undergo no refraction. In the latter, the point is the same with that already determined, Art. 234. It is evident, from what was there demonstrated, that every spherical surface, C P, has two points Q, q in its axis, so related, that all rays converging to or diverging from one of them, shall after refraction *rigorously* converge to or diverge from the other. These points may be called the *aplanatic foci* of the surface; and, to distinguish them, Q may be called the aplanatic focus for incident, and q for refracted rays. To find them in any proposed case, in the axis of any proposed surface C, and *on the concave side* of the surface, take $CQ = (\mu + 1) \times$ radius C E of the surface, and $Cq = \left(\dfrac{1}{\mu} + 1\right) \times$ radius.

Then will Q and q be the aplanatic foci required. In the case of reflexion, when $\mu = -1$, $CQ = Cq = 0$, and both the aplanatic foci coincide with the vertex of the reflector.

288. Aberration shortens the focus for parallel rays

Let us next trace the effect of aberration in lengthening or shortening the focus, for all the varieties of position of the focus of incident rays; and, first, when $D = 0$, or for parallel rays, Δf is of the *same*, and therefore ω of the *contrary* sign with R, and therefore with F, which is equal to $(1 - m)\,.\,R$. Hence it is evident, that the effect of aberration in this case must be to *shorten the focus of exterior rays.*

289. Effect of aberration in other cases. Fig. 54.

Q in this case is infinitely distant. As it approaches the surface, or as the rays from being parallel become more and more *convergent*, or divergent, the aberration diminishes; but the focus of exterior rays is still always *nearer* the surface than that of central, till Q comes up to the *aplanatic focus* A *for incident rays* on the *concave*, or to the focus F of parallel rays *on the convex side*. When Q is at the former of these points, the aberration is 0; at the latter, infinite.

290.

When Q is situated anywhere between these points, however, the reverse is the case, and the effect of aberration is to throw the focus for exterior rays farther from the surface than that for central ones. These results are easily deduced from the consideration of all the particular cases, and hold good for all varieties of curvature, and for refracting media of all kinds. In reflectors, the aplanatic foci coincide with the vertex. In these, the focus for exterior rays is shorter than for interior in every case, except when the radiant point is situated between the surface and the principal focus on the *concave* side of the reflecting surface; but between these points, longer.

291. Aberration of any system of spherical surfaces in contact.

Problem. To determine the aberrations of any system of spherical refracting surfaces placed close together.

Retaining the notation of Art. 257, let us suppose the ray, after passing through the first surface, to be incident on the second. Its aberration at this will arise from two distinct causes: first, that after traversing the first surface, instead of converging to or diverging from the focus for central rays, its direction was really to or from a point in the axis distant from that focus by the total aberration of the first surface; and, secondly, that being incident at a distance from the vertex of the second surface, a new aberration will be produced here, which (being, as well as the other, of small amount) the principles of the differential calculus allow us to regard as independent of it, and which being computed separately, and added to it, gives the whole aberration of the two surfaces regarded as a system. The same is true of the small alterations in the values of f', f'', &c. produced by the aberrations. If then we denote by $\delta f''$ the change in the value of f'', produced by the action of the first surface, and by $\delta' f''$, that arising immediately from the action of the second, and by $\Delta f''$, the total alteration produced by both causes, we shall have

$$\Delta f'' = \delta f'' + \delta' f''$$

Now, first, to investigate the partial alteration $\delta f''$ arising from the total alteration $\Delta f'$ in the value of f', or from the aberration of the first surface, we have

$$f'' = (1 - m)\,.\,R'' + m'' f', \text{ and therefore } \delta f'' = m''\,\Delta f',$$

since, in this case, $\quad D' = D, \quad D'' = f', \quad D''' = f''$, &c.

Again, to discover the partial variation $\delta' f''$ in f'', arising immediately from the action of the second surface, we have, by the equation (c) at once, putting f' for D'', and neglecting y^4, &c.

$$\delta' f'' = \frac{m''(1 - m'')}{2}\,(R'' - f')^2\,\{m''\,R'' - (1 + m'')\,f'\}\,y^2;$$

but we have, by the same equation, also

$$\delta f'' = m''\,\Delta f' = \frac{m''\,m'\,(1 - m')}{2}\,(R' - D)^2\,\{m'\,R' - (1 + m')\,D\}\,y^2.$$

Now it has been shown, (Art. 261,) that $(\mu - 1)(R' - R'')$ expresses the power of the lens, so that, putting L for this, we have

$$\Delta f = \frac{L}{2\mu}(a - \beta D + \gamma D^2)\, y^2. \qquad (m)$$

Such then is the general expression for Δf, the fundamental quantity, from which the aberration ω may be had in any lens by the equation $\omega = -\frac{\Delta f}{f^2}$.

294. Cases in which the aberration of a single lens can be made to vanish.

Corol. 1. The aberration of a lens vanishes when D is so related to R', R'' and μ, as to give

$$a - \beta D + \gamma D^2 = 0; \qquad D = \frac{\beta \pm \sqrt{\beta^2 - 4a\gamma}}{2\gamma}. \qquad (n)$$

Now we find, by substitution and reduction,

$$\beta^2 - 4a\gamma = \mu^2 \{ (R' + R'')^2 - (2\mu + 3\mu^2)(R' - R'')^2 \}$$

and unless this quantity be positive, that is, unless

$$\left(\frac{R' + R''}{R' - R''}\right)^2 > 2\mu + 3\mu^2; \qquad (o)$$

the focus of incident rays cannot be so situated as to render the aberration nothing. But, if the curvatures R' and R'' of the surfaces be such as to satisfy this condition, the value of D may be calculated at once from the equation (*k*.)

295. *Corol.* 2. Whenever, in meniscus or concavo-convex lenses, the difference of the curvatures of the surfaces is small in comparison with their sum, that is, whenever a moderate focal length is produced by great curvatures, the aberration admits of being rendered evanescent by properly placing the focus of incident rays. In a lens of crown glass where $\mu = 1.52$, we have $\sqrt{2\mu + 3\mu^2} = 3.16$; therefore the sum of the curvatures must be at least 3.16 times their difference, to satisfy the condition of possibility. In double-convex or double-concave lenses, R' and R'' having opposite signs, the condition can never be satisfied.

296. No known medium can render the aberration nothing for parallel rays

Corol. 3. If $a = 0$, the aberration vanishes for parallel rays. This condition is, however, only to be satisfied by real values of R' and R'' when μ is equal to or less than $\frac{1}{4}$, and no such media are known to exist.

297. Cases in which the aberration shortens or lengthens the focus.

Corol. 4. The effect of aberration will be to shorten or lengthen the focus for exterior rays, according as the sign of Δf is the same as, or the opposite to, that of f. In particular cases it will, of course, however, depend on the values of μ, R, R', and D which shall take place. The principal case is that of parallel rays, in which $D = 0$, and

$$\Delta f = \frac{y^2}{2\mu} \cdot L \{ (2 - 2\mu^2 + \mu^3) R'^2 + (\mu + 2\mu^2 - 2\mu^3) R' R'' + \mu^3 R''^2 \}$$

and the focus of external rays will be shorter or longer than that of central ones, according as this quantity has the *same*, or *opposite* sign with L, that is, according as

$$(2 - 2\mu^2 + \mu^3) R'^2 + (\mu + 2\mu^2 - 2\mu^3) R' R'' + \mu^3 R''^2$$

is positive or negative. Now, from what we have already seen in the last corollary, this quantity never can be rendered negative by any real values of R' and R'', unless μ be less than $\frac{1}{4}$. For all other media, therefore, (comprehending all yet known to exist in nature,) every lens, whatever be the curvatures of its surfaces, has the exterior focal length for parallel rays shorter than the central.

298. Case of a glass meniscus.

Corol. 5. In a glass *meniscus*, when the radiant point is on the *convex* side, and the rays *diverge*, we have $4 + 3\mu - 3\mu^2$ a positive quantity; and, R' and R'' being both positive, β is so; hence (D being negative in this case) the term $-\beta D$, and therefore the whole factor $a - \beta D + \gamma D^2$ is positive; and L being also positive, Δf is so; and, therefore, ω, the aberration, negative. Hence, when Q is beyond F, the focus for parallel rays incident the other way, the exterior focus is the shorter; but when between F and C, the longer.

299. Rule, for a large class of lenses, to find the effect of aberration in lengthening or shortening the focus.

Corol. 6. Unless $\left(\frac{R' + R''}{R' - R''}\right)^2 > 2\mu + 3\mu^2$, no real value of D can render $a - \beta D + \gamma D^2$ negative.

It appears, therefore, that in all double-convex or concave lenses, as well as in all meniscus and concavo-convex ones, in which the sum of the curvatures of the surfaces is greater than $\sqrt{2\mu + 3\mu^2}$ times their difference, the factor $a - \beta D + \gamma D^2$ is positive for all values of D, and therefore the aberration ω has in all such lenses the sign *opposite* to that of L. Hence, for all such lenses, we have the following simple and general rule: *the effect of aberration will be to throw the focus of exterior rays more* TOWARDS *the incident light than that of central ones, when the lens is of a positive character, or makes parallel rays* CONVERGE, *but more* FROM *the incident light if of a negative, or if it cause parallel rays to* DIVERGE.

300. *Corol.* 7. All other lenses have, as in the case of single surfaces, aplanatic foci, corresponding to the roots of the equation $a - \beta D + \gamma D^2 = 0$. In general there are two such foci of incident and two of refracted rays: and

that is to say

$$\frac{R''}{R'} = \frac{2\mu^2 - \mu - 4}{2\mu^2 + \mu}. \qquad (r)$$

In the case of a glass lens, taking $\mu = 1.5$, this fraction becomes equal to $-\frac{1}{6}$, which shows that the lens must be double-convex, having the curvature of the posterior surface only $\frac{1}{6}$ that of the anterior, or its radius six times as great. Artists sometimes call such a lens a "*crossed lens.*"

306. Case in which this form is plano-convex. *Corol.* 1. If $\mu = 1.6861$, as is nearly the case with several of the precious stones and the more refractive glasses, $R'' = 0$; and the most advantageous figure for collecting all the light in one place is plano-convex, having its convex side turned to the incident rays.

307. Aberrations of various species of lenses determined for parallel rays. *Corol.* 2. Calling the aberration of a lens of the best figure ω, we shall have $\omega = -\frac{15}{14} y^2 \,.\, L$, for glass whose refractive index is 1.5, and the proportional aberrations of other forms will be as follows:

Plano-convex, plane side first (or towards the light)	$4.2 \times \omega$
Plano-convex, curved surface first	$1.081 \times \omega$
Double equi-convex, or concave	$1.567 \times \omega$

308. Aberration of a system of lenses. ***Problem,** To investigate a general expression for the aberration of any system of infinitely thin lenses placed close together in vacuo.*

The general expression for $M \,\Delta f$, or, since $M = 1$ in the case before us, of Δf, is

$$(Q' + Q'' + Q''' + Q^{iv} +, \&c.)\, y^2,$$

which divides itself into terms originating with the successive lenses in the following manner,

$$\Delta f = (Q' + Q'')\, y^2 + (Q''' + Q^{iv})\, y^2 +, \&c.$$

The first of these quantities we have already considered; let us now, therefore, examine the constitution of the rest. Let then μ' be the refractive index of the first lens, μ'' of the second, μ''' of the third; and let α', β', γ' represent the values of α, β, γ for the first lens, or the expressions in (l, 292,) writing only μ' for μ; also let $\alpha'', \beta'', \gamma''$ represent their values for the second lens, or what the same expressions become when μ'' is put for μ; and R''' and R^{iv} respectively for R' and R'', and so on for the rest of the lenses.

309. Now if we consider the values of Q''' and Q^{iv}, it will be seen that they are composed of the quantities m''', m^{iv}, M''', M^{iv}, R''', R^{iv}, f'' and f''', precisely in the same manner that Q' and Q'' are of m', m'', M', M'', R', R'', D and f'.

Moreover, since by Art. 251 we have

$$\begin{aligned}
f' &= (1 - m')\, R' + m' D \\
f'' &= (1 - m'')\, R'' + m'' f' \\
&= (1 - m'')\, R'' + m''\, (1 - m')\, R' + m'' m' D \\
&= (\mu - 1)\, (R' - R'') + D, \text{ since } m' = \frac{1}{\mu},\ m'' = \mu. \\
&= L + D; \text{ call this } D''; \text{ (L is the power of the first lens)} \\
f''' &= (1 - m''')\, R''' + m''' D'' \\
f^{iv} &= (1 - m^{iv})\, R^{iv} + m^{iv} f''' = L'' + D'' \text{ as before; (} L'' \text{ is the power of the second lens)} \\
&= L + L' + D; \text{ and so on.}
\end{aligned}$$

And it is clear that $Q''' + Q^{iv}$ will be the same *function* of, *i. e.* similarly composed of, the refractive index and curvatures of the surfaces of the second lens, and of the quantities D'' and f''', that $Q' + Q''$ is of the refractive index and curvatures of the first lens, and of D and f'. It follows, therefore, that the very same system of reductions which led to the equation

$$Q' + Q'' = \frac{L}{2\mu}\, (\alpha - \beta D + \gamma D^2)$$

being pursued in the case of $Q''' + Q^{iv}$, must lead to the precisely similar equation

$$Q''' + Q^{iv} = \frac{L''}{2\mu''}\, (\alpha'' - \beta'' D'' + \gamma'' D''^2)$$

General expression for it. and so on for the remaining lenses; so that we shall have, ultimately, for the whole system (writing L', D', μ for L, D, μ)

$$\Delta f = \frac{y^2}{2} \left\{ \frac{L'}{\mu'}\, (\alpha' - \beta' D' + \gamma' D'^2) + \frac{L''}{\mu''}\, (\alpha'' - \beta'' D'' + \gamma'' D''^2) + \&c. \right\}; \qquad (s)$$

in which there are as many terms as lenses.

screen full of small round holes, regularly disposed, and, exposing it to the sun, receiving the converged rays on a white paper behind the lens, which should be first placed very near it, and then gradually withdrawn. The pencils which pass through the holes will form spots on the screen, and their disposition will become more and more unequal over the surface, as the screen is further removed; those at the circumference becoming crowded together before the central ones. The manner in which the several spots corresponding to central rays blend together into one image at the focus, and those formed by the exterior ones are scattered round it, gives us a very good idea of the variation of density of the rays in the circle of aberration at or near the principal focus; and if the white screen be waved rapidly to and fro in the cone of rays, so as to pass over the focus at each oscillation, the whole cone will be seen as a solid figure in the air, and the place of the circle of least aberration will become evident to the eye, forming altogether a very pleasing and instructive experiment.

§ XI. *Of the Foci for Oblique Rays, and of the Formation of Images.*

318. We have hitherto considered rays as converging to, or diverging from, a single point; but as this is not the case with luminous bodies of a sensible diameter, we now proceed to examine the cases of refraction at spherical surfaces, where more than one radiant point is concerned, or where several pencils are incident at once on the surface. We shall take for our positive, or fundamental case, as we have done all along, that of *converging* rays incident on the convex side of a more refractive medium than the ambient one, and derive all others from it by the changes in the sign and relative magnitudes of R, D, &c.

Foci of oblique pencils.

In fig. 56, then, let Q and Q′ be the foci of two pencils of convergent rays incident on the spherical surface C C′, whose centre is E. Draw Q E C, Q′ E C′, cutting the surface in C and C′, and, regarding C E Q as the axis of the pencil R Q, S Q, T Q, the focus of refracted rays will be found by taking q, such as that $\frac{1}{\mathrm{C}\,q}$, or f, shall be equal to $(1-m)\,\mathrm{R}+m\,\mathrm{D}$, (247, *e.*) Similarly, regarding C′ E Q′ as the axis of the pencil converging to Q′, the focus q' will be had by the equation

$$\frac{1}{\mathrm{C}'q'}=f'=(1-m)\,\mathrm{R}+m\,\mathrm{D}'.$$

Thus when C′ Q′ = C Q, C q' will also equal C q, and, in general, when the locus of the point Q is given, that of q may be found.

319. Images in Optics defined. *Definition.* The image of an object, in Optics, is the locus of the focus of a pencil of rays diverging from, or converging to, every point of it, and received on a refracting surface. Thus, supposing C Q′ to be a line, or surface, every point of which may be regarded as a focus of incident rays, $q\,q'$ is its image.

320. Form of the image of a straight line. *Problem. To find the form of the image of a straight line formed by a spherical refracting or reflecting surface.*

Put $\mathrm{C\,E}=r;\quad \mathrm{C\,Q}=a;\quad \mathrm{E\,M}=x;\quad \mathrm{M}\,q'=y;\quad \mathrm{E}\,q'=\sqrt{x^2+y^2};\quad \mathrm{C'Q'}=a'.$

Then we have

$$\frac{1}{\mathrm{C}'q'}=\frac{1-m}{r}+\frac{m}{a'}=\frac{(1-m)\,a'+m\,r}{r\,a'};$$

and therefore

$$\mathrm{C}'q'=\frac{r\,a'}{(1-m)\,a'+m\,r};\qquad \mathrm{E}\,q'=\frac{m\,r\,(a'-r)}{(1-m)\,a'+m\,r};$$

we have, consequently,

$$x^2+y^2=\frac{m^2\,r^2.\,(a'-r)^2}{\{(1-m)\,a'+m\,r\}^2}.$$

But, by similar triangles, E q' : E M : : E Q′ : E Q, or

$$x^2+y^2=\frac{(a'-r)^2.\,x^2}{a^2},$$

equating these two values we get

$$\frac{a}{x}=\frac{(1-m)\,a'+m\,r}{m\,r};\qquad a'=\frac{m}{1-m}\cdot\frac{r\,(a-x)}{x};$$

Is a conic section.

so that eliminating a', by substituting this value for it, we get for a final equation between x and y, or for the equation of the image

$$(1-m)^2\,(x^2+y^2)=\left(\frac{r}{a}\right)^2.\,(m\,a-x)^2$$

which belongs to a conic section.

321. *Problem. When an oblique pencil is incident on any system of spherical surfaces, to find the focus of refracted rays.*

latter situation the emeried glass may even be removed altogether, and the image will still be seen, and even more distinctly, as if a real object stood in the place in all respects similar to the picture.

332. We may examine the image on the roughened glass with a magnifying glass, or microscope. It will then appear as a delicate painting, accommodating itself to all the inequalities of the surface. But if, in the act of so examining it, the rough glass be removed, the painting remains as if suspended in air, and the objects it represents are seen brought nearer to the eye, and enlarged in their dimensions. In short, we have formed a telescope.

333. If the lens used to form the image be a concave one, or if a convex reflector be used, as in fig. 64 and 65, the rays, after refraction or reflexion, diverge, not from any actual points in which they cross, but from points in which they would cross if produced backwards. There is in this case, then, no real image formed capable of being received on a screen, but what is called *a virtual one*, visible to the eye if properly situated, either unassisted or aided by a magnifier, and situated on the same side of the lens, or on the contrary side of the reflector with the object, and therefore *erect*.

334. The perfection of the image formed by a lens or reflector, its exact resemblance to the object, and the distinctness of its parts, will depend on the exact convergence of all the rays of pencils emanating from every physical point of the object in strict mathematical points, or in as near an approach to such points as may be. If, therefore, a lens of considerable diameter be used, especially if the curvatures of its surfaces be improperly chosen so as to produce much aberration, the image will be confused; for each point of the object will form, not a point, but a small circular spot in the image, over which the rays are diffused; and as these spots overlap and encroach on each other, distinctness is destroyed. For the formation, therefore, of perfect images, the destruction of aberration is the essential condition; and whatever imperfections, either in the figures of the reflecting or refracting surfaces used, or in the materials of which they are composed, tends to throw the rays aside from their strict geometrical direction, must, of course, confound the images. Hence, in the formation of optical images, there are three great points to be attended to: first, perfect polish of the surfaces; secondly, perfect homogeneity in the material employed; thirdly, strict conformity in the figures of the reflecting and refracting surfaces to geometrical rules, and the results of analysis.

335. There is one case where the aberrations of all kinds are rigorously destroyed, and in which the image is perfect. It is when the rays are reflected at a plane surface. For (fig. 66) if P Q be an object placed before a plane reflector A B, and if perpendiculars be let fall from every point of the object to the surface, and on the other side points in these be taken at the same distances respectively behind the surface as *p*, *q*, these points will form the image. Now we have seen, that all rays from any point P, reflected at A B, will after reflexion diverge strictly from *p* its image. Thus, the image is as perfect and free from aberration as the object; and will appear, to an eye placed so as to receive the rays, like a real object placed behind the reflector.

336. *Corol.* The image formed by a plane reflecting surface is similar and equal to the object, and any corresponding lines in both are equally inclined to the reflecting surface. A common looking-glass is the best illustration of this case.

337. *Proposition.* To determine the image of any object formed by a plane refracting surface. Let B C be the surface, P Q the object. From any point Q draw Q C perpendicular to the surface, and, μ being the index of refraction, if we regard the surface as a sphere of infinite radius, we have R its curvature $= 0$, and the equation

$f = (1 - m)\,\mathrm{R} + m\,\mathrm{D}$ becomes simply $f = m\,\mathrm{D}$. Now $f = \dfrac{1}{\mathrm{C}q}$; $\mathrm{D} = \dfrac{1}{\mathrm{CQ}}$; and $m = \dfrac{1}{\mu}$. Hence

this equation, translated into geometrical language, gives $\mathrm{C}q = \mu \times \mathrm{CQ}$.

338. In the case represented in the figure, the refraction is made out of a denser medium into a rarer, the object being immersed in the denser (as under water), and the eye of a spectator in the rarer (as in air): the image *q* of the point Q is therefore nearer the surface than Q, (because in this case μ is less than unity.) The same holds good of all other points of the image; so that the whole object will appear raised by refraction, as in the familiar experiment where a shilling is laid in an empty vessel, and the eye withdrawn till the shilling is hidden by the edge, but reappears again, as if raised up, when the vessel is filled with water. On the other hand, to an eye placed under water, external objects would appear farther removed by the effect of refraction.

339. *Corol.* 1. The image of a straight line P Q in the object is a straight line *p q* in the image, less inclined to the surface if the refraction be made from a denser into a rarer medium. Thus, if a stick D A P Q be partly plunged into water, the immersed portion A Q forms the image A *q* less inclined; so that to a spectator in air, the stick appears broken and bent upwards at A. The appearance is familiar to every one.

340. In refraction at a plane surface, however, the rays do not rigorously diverge from, or converge to, a single point. Therefore the above result is only approximately correct, and supposes the rays to be incident nearly at right angles to the surface. And this leads us to the consideration of oblique vision through refracting surfaces, or in reflectors of any figure.

341. Oblique vision through refracting or reflecting surfaces of any figure. Fig. 68.

The eye sees by the rays which enter it, and judges of the existence of an object, by the fact of rays diverging sensibly from some point in space. If, then, rays diverge rigorously from a point, the eye which receives them is irresistibly led to the belief (unless corrected by experience and judgment) of an object being there; the illusion is complete, and vision perfect. But if such divergence be only approximate, as when the density of the rays which reach the eye in any one direction is very much greater than in directions adjacent on either side, vision is still produced, only less distinct, in proportion to the degree of deviation from strict mathematical divergence of the rays which produce it. Suppose, now, Q to be a radiant point placed anywhere with respect to the refracting or reflecting surface A C B, (fig. 68,) and let A *q* F B be the caustic formed by the intersection of all the refracted or reflected rays. Let us suppose an eye placed at E, and from thence draw E *q* a tangent magnitude of the lens seen from the image, alone, whatever be the distance of the object. Now the apparent magnitude of the lens seen from the image is always much less than a hemisphere. Therefore (even supposing no light lost by reflection or refraction) the illumination of the image is always much less than that of the object. This is the case when the image is received on a screen which reflects all the rays, or when viewed by an eye behind it having a pupil large enough to receive all the rays which have crossed at the image, *à fortiori*, then, when the eye does not receive all the rays, must the apparent intrinsic brightness be less than that of the object. This supposes the object to have a sensible magnitude; but when both the object and its image are physical points, the eye judges only of absolute light; and the light of the image is therefore proportional to the apparent magnitude of the lens, as seen from the object. In the case of a star, for instance, whose distance is constant, the absolute light of the image is simply as the square of the aperture, and this is the reason why stars can be seen in large telescopes which are too faint to be seen in small ones.

Images are never so bright as their objects

§ XII. *Of the Structure of the Eye, and of Vision.*

350. It is by means of optical images that vision is performed, that we see. The eye is an assemblage of lenses which concentrate the rays emanating from each point of external objects on a delicate tissue of nerves, called the retina, there forming an image, or exact representation of every object, which is the thing immediately perceived or *felt* by the retina.

Description of the eye. Fig. 70. Aqueous humour. Its composition. Refractive power. Cornea. Its figure an ellipsoid of revolution.

Fig. 70 is a section of the human eye through its axis in a horizontal plane. Its figure is, generally speaking, spherical, but considerably more prominent in front. It consists of three principal chambers, filled with media of perfect transparency and of refractive powers, differing sensibly *inter se*, but none of them greatly different from that of pure water. The first of these media, A, occupying the anterior chamber, is called the *aqueous humour*, and consists, in fact, chiefly of pure water, holding a little muriate of soda and gelatine in solution, with a trace of albumen; the whole not exceeding eight per cent.* Its refractive index, according to the experiments of M. Chossat,† and those of Dr. Brewster and Dr. Gordon,‡ is almost precisely that of water, viz. 1.337, that of water being 1.336. The cell in which it is contained is bounded, on its anterior side, by a strong, horny, and delicately transparent coat *a*, called the *cornea*, the figure of which, according to the delicate experiments and measures of M. Chossat,§ is an ellipsoid of revolution about the major axis; this axis, of course, determines the *axis of the eye;* but it is remarkable, that in the eyes of oxen, measured by M. Chossat, its vertex was never found to be coincident with the central point of the aperture of the cornea, but to lie always about 10° (reckoned on the surface) inwardly, or towards the nose, in a horizontal plane. The ratio of the semi-axis of this ellipse to the excentricity, he determines at 1.3; and this being nearly the same with 1.337, the index of refraction, it is evident, from what was demonstrated in Art. 236, that parallel rays incident on the cornea in the direction of its axis, will be made to converge to a focus situated behind it, almost with mathematical exactness, the aberration which would have subsisted, had the external surface a spherical figure, being almost completely destroyed.

351. Iris.

The posterior surface of the chamber A of the aqueous humour is limited by the *iris* $\beta\,\gamma$, which is a kind of circular opaque screen, or diaphragm, consisting of muscular fibres, by whose contraction or expansion an aperture in its centre, called the *pupil*, is diminished or dilated, according to the intensity of the light. In very strong lights the opening of the pupil is greatly contracted, so as not to exceed twelve hundredths of an inch in the human eye, while in feebler illuminations it dilates to an opening not exceeding twenty-five hundredths,‖ or double its former diameter. The use of this is evidently to moderate and equalize the illumination of the image on the retina, which might otherwise injure its sensibility. In animals (as the cat) which see well in the dark, the pupil is almost totally closed in the daytime, and reduced to a very narrow line; but in the human eye, the form of the aperture is always circular. The contraction of the pupil is involuntary, and takes place by the effect of the stimulus of the light itself; a beautiful piece of self-adjusting mechanism, the play of which may be easily seen by approaching a candle to the eye while directed to its own image in a looking-glass.

352. Crystalline. Its figure.

Immediately behind the opening of the *iris* lies the *crystalline lens*, B, enclosed in its *capsule*, which forms the posterior boundary of the chamber A. Its figure is a solid of revolution, having its anterior surface much less curved than the posterior. Both surfaces, according to M. Chossat, are ellipsoids of revolution about their *lesser* axes; but it would seem from his measures, that the axes of the two surfaces are neither exactly coincident in direction with each other, nor with that of the cornea. This deviation would be fatal to distinct vision were the crystalline lens very much denser than the others, or were the whole refraction performed by it. This, however, is not the case; for the mean refractive index of this lens is only 1.384, while that of the aqueous humour, as we have seen, is 1.337; and that of the *vitreous* C, which occupies the third chamber, is 1.339; so that the whole amount of bending which the rays undergo at the surface of the crystalline is small, in comparison with the inclination of the surface at the point where the bending takes place, and, since near the vertex, a

Refraction. Non-coincidence of the axes of its surfaces.

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* Chenevix, *Philosophical Transactions*, vol. xciii. p. 195.

† *Bulletin de la Soc. Philomatique*, 1818, p. 94.

‡ *Edinburgh Philosophical Journal*, vol. i. p. 42.

§ *Sur la Courbure des Milieux Réfringens de l'Œil chez le Bœuf. Annales de Chim.* x. p. 337.

‖ Dr. Young's Lectures on the Mechanism of the Eye, *Philosophical Transactions*, vol. xci.

material deviation in the direction of the axis can produce but a very minute change in the inclination of the ray to the surface, this cause of error is so weakened in its effect, as, probably, to produce no appreciable aberration. Why not injurious to vision.

353. Composition of crystalline. Denser towards centre.

The crystalline is composed of a much larger proportion of albumen and gelatine than the other humours of the eye, so much so as to be entirely coagulable by the heat of boiling water. It is somewhat denser towards the centre than at the outside. According to Dr. Brewster and Dr. Gordon, the refractive indices of its centre middle of its thickness, from the centre to the outside, and the outside itself, are respectively 1.3999, 1.3786, and 1.3767, that of pure water being 1.3358. This increase of density is obviously useful in correcting the aberration, by shortening the focus of rays near the centre, according to the rule laid down in Art. 299 for finding the effect of aberration. The effect of the elliptic figure of the surfaces is, however, a matter of pretty complex calculation, and cannot be entered upon in the limits of this essay. Its use is, probably, to correct the aberration of oblique pencils.

354. The posterior chamber C of the eye is filled with the *vitreous humour*, a fluid differing (according to Chenevix) neither in specific gravity nor in chemical composition in any sensible respect from the aqueous; and, as we have already seen, having a refractive index but very little superior to it.

355. Retina.

The refractive density of the crystalline being superior to that of either the aqueous or vitreous humour, the rays which are incident on it in a state of convergence from the cornea, are made to converge more, and exactly in their final focus is the posterior surface of the cell of the vitreous humour covered by the retina *d*, a network (as its name imports) of inconceivably delicate nerves, all branching from one great nerve O, called the optic nerve, which enters the eye obliquely at the inner side of the orbit, next the nose. The retina lines the whole of the cavity C up to *i*, where the capsule of the crystalline commences. Its nerves are in contact with, or immersed in, the *pigmentum nigrum*, a very black velvety matter, which covers the *choroid membrane g*, and whose office is to absorb and stifle all the light which enters the eye as soon as it has done its office of exciting the retina; thus preventing internal reflexions, and consequent confusion of vision. The whole of these humours and membranes are contained in a thick tough coat, called the *sclerotica*, which unites with the cornea, and forms what is commonly called the *white of the eye*. Sclerotica.

356. Change of focus of eye for near objects.

Such is the structure by which parallel rays, or those emanating from very distant objects, are brought to a focus on the retina. But as we require to see objects near, as well as at a distance, and as the focus of a lens or system of lenses for near objects is longer than for distant ones, it is evident that a power of adjustment must reside somewhere in the eye; by which either the retina can be removed farther from the cornea, and the eye lengthened in the direction of its axis, or the curvature of the lenses themselves altered so as to give greater convergency to the rays. We know that such a power exists, and can be called into action by a voluntary effort; and, evidently, by a muscular action, producing fatigue if long continued, and not capable of being strained beyond a certain point. Anatomists, however, as well as theoretical opticians, differ as to the mechanism by which this is effected. Some assert, that the action of the muscles which move the eye in its orbit, called the *recti*, or straight muscles, when all contracted at once, producing a pressure on the fluids within, forces out the cornea, rendering it at once more convex, and more distant from the retina. This opinion, however, which has been advocated by Dr. Olbers, and even attempted to be made a matter of ocular demonstration by Ramsden and Sir E. Home, has been combated by Dr. Young, by experiments which show, at least, very decisively, that the increase of convexity in the cornea has little if any share in producing the effect. An elongation of the whole eye, spherical as it is and full of fluid, to the considerable extent required, is difficult to conceive as the result of any pressure which could be safely applied, as to give distinct vision at the distance of three inches from the eye, (the nearest at which ordinary eyes can see well,) the sphere must be reduced to an ellipsoid, having its axis nearly one-seventh longer than in its natural state; and the extension of the sclerotica thus produced, would hardly seem compatible with its great strength and toughness. Another opinion, which has been defended with considerable success by the excellent philosopher last named, is, that the crystalline itself is susceptible of a change of figure, and becomes more convex when the eye adapts itself to near distances. His experiments, on persons deprived of this lens, go far to prove the total want of a power to change the focus of the eye in such cases, though a certain degree of adaptation is obtained by the contraction of the iris, which, limiting the diameter of the pencil, diminishes the space on the retina over which imperfectly converged rays are diffused, and thus, in some measure, obviates the effect of their insufficient convergence. When we consider that the crystalline lens has actually a regular fibrous structure, (as may be seen familiarly on tearing to pieces the lens of a boiled fish's eye,) being composed of layers laid over each other like the coats of an onion, and each layer consisting of an assemblage of fibres proceeding from two poles, like the meridians of a globe, the axis being that of the eye itself; we have, so far at least, satisfactory evidence of a muscular structure; and were it not so, the analogy of pellucid animals, in which no muscular fibres can be discerned, and which yet possess the power of motion and obedience to the nervous stimulus, though nerves no more than muscles can be seen in them, would render the idea of a muscular power resident in the crystalline easily admissible, though nerves have as yet not been traced into it. On the whole, it must be allowed, that the presumption is strongly in favour of this mechanism, though the other causes already mentioned may, perhaps, conspire to a certain extent in producing the effect, and though the subject must be regarded as still open to fuller demonstration. It is the boast of science to have been able to trace so far the refined contrivances of this most admirable organ; not its shame to find something still concealed from its scrutiny; for, however anatomists may differ on points of structure, or physiologists dispute on modes of action, there is that in what we *do* understand of the formation of the eye so similar, and yet so infinitely superior, to a product of human ingenuity,—such thought, such care, such refinement, such advantage taken of the properties of natural agents used as mere instruments, for accomplishing a given end, as force upon us a conviction of deliberate choice and premeditated design, more strongly, perhaps, than any single contrivance to be found, whether in art or nature, and render its study an object of the deepest interest.

357. Image on the retina the immediate object of vision.

The images of external objects are of course formed inverted on the retina, and may be seen there, by dissecting off the posterior coats of the eye of a newly-killed animal, and exposing the retina and choroid membrane from behind, like the image on a screen of rough glass, mentioned in Art. 331. It is this image, and this only, which is *felt* by the nerves of the retina, on which the rays of light act as a stimulus; and the impressions therein produced are thence conveyed along the optic nerves to the sensorium, in a manner which we must rank at present among the profounder mysteries of physiology, but which appears to differ in no respect from that in which the impressions of the other senses are transmitted. Thus, a paralysis of the optic nerve produces, while it lasts, total blindness, though the eye remains open, and the lenses retain their transparency; and some very curious cases of half blindness have been successfully referred to an affection of one of the nerves without the other.* On the other hand, while the nerves retain their sensibility, the degree of perfection of vision is exactly commensurate to that of the image formed on the retina. In cases of cataract, where the crystalline lens loses its transparency, the light is prevented from reaching the retina, or from reaching it in a proper state of regular concentration, being stopped, confused, and scattered by the opaque or semi-opaque portions it encounters in its passage. The image, in consequence, is either altogether obliterated, or rendered dim and indistinct; and the progress of blindness is accordingly. If the opaque lens be extracted, the full perception of light returns; but one principal instrument for producing the convergence of the rays being removed, the image, instead of being formed *on* the retina, is formed considerably behind it, and the rays being received in their unconverged state on it, produce no regular picture, and therefore no distinct vision. But if we give to the rays, before their entry into the eye, a certain proper degree of convergence, by the application of a convex lens, so as to render the remaining lenses capable of finally effecting their exact convergence on the retina, restoration of distinct vision is the immediate result. This is the reason why persons who have undergone the operation for the cataract (which consists either in totally removing, or in putting out of the way an opaque crystalline) wear spectacles of comparatively very short focus. Such glasses perform the office of an artificial crystalline. A similar imperfection of vision to that produced by the removal of the crystalline, is the ordinary effect of old age, and its remedy is the same. In aged persons the exterior transparent surface of the eye, called the *cornea*, loses somewhat of its convexity, and becomes flatter. The *power* of the eye is therefore diminished, (Art. 248 and 255,) and a perfect image can no longer be formed on the retina. The deficient power is however supplied by a convex lens, or *spectacle-glass*, (Art. 268,) and vision rendered perfect or materially improved.

358. Short-sighted persons have their eyes too convex, and this defect is, like the other, remediable by the use of proper lenses of an opposite character. There are cases, however, though rare, in which the cornea becomes so very prominent as to render it impossible to apply conveniently a lens sufficiently concave to counteract its action. Such cases would be accompanied with irremediable blindness, but for that happy boldness, justifiable only by the certainty of our knowledge of the true nature and laws of vision, which in such a case has suggested the opening of the eye and removal of the crystalline lens, though in a perfectly sound state.

359. Malconformations of the cornea.

But these are not the only cases of defective vision arising from the structure of the organ, which are susceptible of remedy. Malconformations of the cornea are much more common than is generally supposed, and few eyes are, in fact, free from them. They may be detected by closing one eye, and directing the other to a very narrow, well-defined luminous object, not too bright, (the horns of the moon, when a slender crescent, only two or three days old, are very proper for the purpose,) and turning the head about in various directions. The line will be doubled, tripled, or multiplied, or variously distorted; and careful observation of its appearances, under different circumstances, will lead to a knowledge of the peculiar conformation of the refracting surfaces of the eye which causes them, and may suggest their proper remedy.

Remarkable case, successfully remedied by glasses.

A remarkable and instructive instance of the kind has recently been adduced by Mr. G. B. Airy, (*Transactions of the Cambridge Philosophical Society*,) in the case of one of his own eyes; which, from a certain defect in the figure of its lenses, he ascertained to refract the rays to a nearer focus in a vertical than in a horizontal plane, so as to render the eye utterly useless. This, it is obvious, would take place if the cornea, instead of being a surface of revolution, (in which the curvature of all its sections through the axis must be equal,) were of some other form, in which the curvature in a vertical plane is greater than in a horizontal. It is obvious, that the correction of such a defect could never be accomplished by the use of spherical lenses. The strict method, applicable in all such cases, would be to adapt a lens to the eye, of nearly the same refractive power, and having its surface next the eye an exact *intaglio* fac-simile of the irregular cornea, while the external should be exactly spherical of the same general convexity as the cornea itself; for it is clear, that all the distortions of the rays at the posterior surface of such a lens would be exactly counteracted by the equal and opposite distortions at the cornea itself.† But the necessity of limiting the correcting lens to such surfaces as can be truly ground in glass, to render it of any real and everyday use, and which surfaces are only spheres, planes, and cylinders, suggested to Mr. Airy the ingenious idea of a double concave lens, in which one surface should be spherical, the other cylindrical. The use of the spherical surface was to correct the general defect of a too convex cornea. That of the cylindrical may be thus explained. Suppose parallel rays incident on a concave cylindrical surface, A B C D, in a direction perpendicular to its axis, as in fig. 71, and let S S′ P P′ Q Q′ T T′, be any laminar pencil of them contained in a parallelepiped infinitely

Fig. 71.

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* Wollaston, on Semi-decussation of the Optic Nerves, *Philosophical Transactions*, 1824.

† Should any very bad cases of irregular cornea be found, it is worthy of consideration, whether at least a temporary distinct vision could not be procured, by applying in contact with the surface of the eye some transparent animal jelly contained in a spherical capsule of glass; or whether an actual mould of the cornea might not be taken, and impressed on some transparent medium. The operation would, of course, be delicate, but certainly less so than that of cutting open a living eye, and taking out its contents.

thin, and having its sides parallel to the axis. Any of the rays S P, S′ P′, of this pencil lying in a plane A P S perpendicular to the axis, will after refraction converge to, or diverge from, a point X, also in this plane; and, therefore, all the rays incident on P Q, P′ Q′, will after refraction have for their focus the line X Y, in the caustic surface A F G D, and the principal focus of the cylinder will be the line F G, whose distance from the vertex C C′ of the surface, or F C, is the same with the focal length of a spherical surface, formed by the revolution of A B about the axis F C. Thus we see that a cylindrical lens produces no convergency or divergency in parallel rays, incidental in the plane of its axis; while it converges or diverges rays in a plane at right angles to the axis, as a spherical surface of equal curvature would do If then such a cylindrical surface be conjoined with a spherical one, the focus of the spherical surface will remain unaltered in one plane, but in the other will be changed to that of a lens formed by it, and a spherical surface of equal curvature with the cylinder. Hence by properly placing such a cylindro-spheric lens across the defective eye, its defect will be (approximately, at least) counteracted. It would be wrong to conclude our account of this interesting application of mathematical knowledge to the increase of the comforts and improvement of the faculties of its possessor, in other than his own words. "After some ineffectual applications to different workmen, I at last procured a lens to these dimensions,* from an artist named Fuller, at Ipswich. It satisfies my wishes in every respect. I can now read the smallest print at a considerable distance with the left" (the defective) "eye as well as with the right. I have found that vision is most distinct when the cylindrical surface is turned from the eye: and as, when the lens is distant from the eye, it alters the apparent figure of objects by refracting differently the rays in different planes, I judged it proper to have the frame of my spectacles made so as to bring the glass pretty close to the eye. With these precautions, I find that the eye which I once feared would become quite useless, can be used in almost every respect as well as the other."

360. Blindness, partial or total, may be caused, not only by the opacity of the crystalline lens, but of any other part, or by anything extraneous to the materials of which they consist, interposed between the external transparent surface of the cornea and the retina. In all such cases, if the sensibility of the nerve be uninjured, the restoration of sight is never to be despaired of. In a recent most remarkable case, operated by Mr. Wardrop, and by him recorded in the *Philosophical Transactions for* 1826, blindness from infancy, accompanied with complete obliteration of the pupil, by a contraction of the iris, owing to an unskilful operation, performed at six months of age, was removed, and perfect sight restored after a lapse of forty-six years, by a simple removal of the obstruction, by breaking a hole through the closed membrane. The details of this case are in the highest degree interesting, but we must refer the reader to the volume of the *Philosophical Transactions* cited for the account.

361. Single vision with two eyes.

As we have two eyes, and a separate image of every external object is formed in each, it may be asked, *why do we not see double?* and to some, the question has appeared to present much difficulty. To us it appears, that we might with equal reason ask, *why*—having two hands, and five fingers on each, all endowed with equal sensibility of touch and equal aptitude to discern objects by that sense—*we do not feel decuple?* The answer is the same in both cases: it is a matter of habit. Habit alone teaches us that the sensations of sight correspond to any thing external, and to what they correspond. An object (a small globe or wafer suppose) is before us on a table; we direct our eyes to it, *i. e.* we bring its images on both retinæ to those parts which habit has ascertained to be the most sensible and best situated for seeing distinctly; and having always found that in such circumstances the object producing the sensation is one and the same, the idea of unity in the object becomes irresistibly associated with the impression. But while looking at the globe, squeeze the upper part of one eye downwards, by pressing on the eyelid with the finger, and thereby forcibly throw the image on another part of the retina of that eye, and double vision is immediately produced, two globes or two wafers being distinctly seen, which appear to recede from each other as the pressure is stronger, and approach, and finally blend into one as it is relieved. The same effect may be produced without pressure, by directing the eyes to a point nearer to, or farther from them than the wafer; the optic axis in this case being both directed away from the object seen. When the eyes are in a state of perfect rest, their axes are usually parallel, or a little diverging. In this state all near objects are seen double; but the slightest effort of attention causes their images to coalesce immediately. Those who have one eye distorted by a blow, see double, till habit has taught them anew to see single, though the distortion of the optic axis subsists.

Double vision artificially produced.

Another method.

362. Single objects felt double in certain cases

The case is exactly the same with the sense of touch. Lay hands on the globe, and handle it. It is *one*, nothing can be more irresistible than this conviction. Place it between the first and second fingers of the right hand in their natural position. The right side of the first and left of the second finger feel opposite convexities; but as habit has always taught us that two convexities so felt belong to one and the same spherical surface, we never hesitate or question the identity of the globe, or the unity of the sensation. Now cross the two fingers, bringing the second over the first, and place the globe on the table in the fork between them, so as to feel the left side of the globe with the right side of the second finger, and the right with the left of the first. In this state of things the impression is equally irresistible, that we have two globes in contact with the fingers, especially if the the eyes be shut, and the fingers placed on it by another person. A pea is a very proper object for this experiment. The illusion is equally strong when the two fore fingers of both hands are crossed, and the pea placed between them.

363. Force of habit in producing single vision illustrated by experiment.

So forcible is the power of habit in producing single vision, that it will bring the two images to apparent coalescence, when the rays which form one of them are really turned far aside from their natural course. To show this, place a candle at a distance, and look at it with one eye (the left suppose) naked, the other having before it a prism, with a variable refracting angle, (an instrument to be described hereafter, see INDEX,) and, first, let the angle be adjusted to zero, then will the prism produce no deviation, and the object will appear single. Now vary the prism, so as to produce a deviation of 2° or 3° of the rays in a horizontal plane to the right. The candle will immediately be seen double, the image deviated by the prism being seen to the left of the other; but the slightest motion, such as winking with the eyelids, blends them immediately into one. Again, vary the prism a few degrees more in the same direction; the candle will again be doubled, and again rendered single by winking, and directing the attention more strongly to it; and thus may the optic axes be, as it were, inveigled to an inclination of 20° or 30° to each other. In this state of things, if a second candle be placed exactly in the direction of the deviated image of the first, but so screened, that its rays shall not fall on the left eye, and the prism be then suddenly removed in the act of winking, the two candles appear as one. If the deviation of the image seen with the right eye be made to the apparent right, the range within which it is possible to bring them to coalesce is much more limited, as it is much more usual for us to direct by an effort the optic axes towards, than from each other. If the deviation be made but a very little out of the horizontal plane, no effort will enable us to correct it. It is probable that some cases of squinting might be cured by some such exercise in the art of directing the optic axes, if continued perseveringly.

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* Radius of the spherical surface 3⅓ inches, of the cylindrical 4½.

364. A further cause of single vision. Nervous sympathy.

Such is, undoubtedly, a sufficient explanation of single vision with two eyes; yet Dr. Wollaston has rendered it probable that a physiological cause has also some share in producing the effect, and that a semi-decussation of the optic nerves takes place immediately on their quitting the brain, half of each nerve going to each eye, the right half of each retina consisting wholly of fibres of one nerve, and the left wholly of the other, so that all images of objects out of the optic axis are perceived by one and the same nerve in both eyes, and thus a powerful sympathy and perfect unison kept up between them, independent of the mere influence of habit. Immediately in the optic axis, it is probable, that the fibres of both nerves are commingled, and this may account for the greater acuteness and certainty of vision in this part of the eye.

365. Erect vision by an inverted image.

Another point, on which much more discussion has been expended than it deserves, is the fact of our seeing objects erect when their images on the retina are inverted. Erect, means nothing else than having the head farther from the ground, and the feet nearer, than any other part. Now, the earth, and the objects which stand on it, preserve the same relative situation in the picture on the retina that they do in nature. In that picture, men, it is true, stand with their heads downwards; but then, at the same time, heavy bodies fall upwards; and the mind, or its deputy, the nerve, which is present in every part of the picture, judges only of the relations of its parts to one another. How these parts are related to external objects, is known only by experience, and judged of at the instant only by habit.

366. *Punctum cæcum.*

There is one remarkable fact which ought not to escape mention, even in so brief an abstract of the doctrine of vision as the present, it is, that the spot ○, at which the optic nerve enters the eye, is totally insensible to the stimulus of light, for which reason it is called the *punctum cæcum.* The reason is obvious: at this point the nerve is not yet divided into those almost infinitely minute fibres, which are fine enough to be either thrown into tremors, or otherwise changed in their mechanical, chemical, or other state, by a stimulus so delicate as the rays of light. The effect, however, is curious and striking. On a sheet of black paper, or other dark ground, place two white wafers, having their centres three inches distant. Vertically above that to the *left,* hold the *right* eye, at 12 inches from it, and so that when looking down on it, the line joining the two eyes shall be parallel to that joining the centre of the wafers. In this situation closing the left eye, and looking full with the right at the wafer perpendicularly below it, this only is seen, the other being completely invisible. But if removed ever so little from its place, either to the right or left, above or below, it becomes immediately visible, and starts, as it were, into existence. The distances here set down may perhaps vary slightly in different eyes.

Experiment proving its existence.

367. It will cease to be thought singular, that this fact, of the absolute invisibility of objects in a certain point of the field of view of each eye, should be one of which not one person in ten thousand is apprized, when we learn, that it is not extremely uncommon to find persons who have for some time been totally blind with one eye without being aware of the fact. One instance has fallen under the knowledge of the writer of these pages.

368. Eyes of fishes.

In the eyes of fishes, the humours being nearly of the refractive density of the medium in which they live, the refraction at the cornea is small, and the work of bringing the rays to a focus on the retina is almost wholly performed by the crystalline. This lens, therefore, in fishes is almost spherical, and of small radius, in comparison with the whole diameter of the eye. Moreover, the destruction of spherical aberration not being producible in this case by mere refraction at the cornea, the crystalline itself is adapted to execute this necessary part of the process, which it does by a very great increase of density towards the centre. (Brewster, *Treatise on New Philosophical Instruments,* p. 268.) The fibrous and coated structure of the crystalline lens is beautifully shown in the eye of a fish coagulated by boiling.

369. The same scientific principles which enable us to assist natural imperfections of sight, can be employed in giving additional power to this sense, even in individuals who enjoy it naturally in the greatest perfection. It being once understood, that the image on the retina is that which we really *see,* it follows, that if by any means we can render this image brighter, larger, more distinct than in the natural state of the organ, we shall see objects brighter than in their natural state, enlarged in dimension, and, therefore, capable of being examined more in detail, or more sharply defined and clearly outlined. The means which the principles already detailed put in our power, for the accomplishment of such ends, are the concentration of more rays than enter the natural eye by lenses; the enlargement of the image on the retina, by substituting for the object seen an image of it, either larger than the object itself, or capable of being brought nearer to us; and the destruction of aberration, by properly adapting the figure and materials of our instruments to the end proposed.

370. *Proposition.* The apparent magnitude of a rectilinear object is measured by the angle subtended by it a

the centre of the eye, or by the linear magnitude of its image on the retina, and is therefore proportional to $\frac{\text{linear magnitude of object}}{\text{its distance from the eye}}$.

The *centre* of the eye, in its optical sense, is a point nearly in the centre of the pupil in the plane of the iris, and the image of any external object P Q, being formed at the bottom of the eye at $p\,q$, by rays crossing there, must subtend the same angle; so that $p\,q = \mathrm{P\,Q} \, . \, \frac{p\,\mathrm{E}}{\mathrm{P\,E}}$. Fig. 72.

371. *Corol.* If the object be so distant that the rays from each point of it may be regarded as parallel, the angular diameter of the object is measured by the inclination of rays of its extreme pencils to each other. Whenever, therefore, the eye sees by parallel, or very nearly parallel, rays, the apparent magnitude of the object seen, is measured by the inclination of its extreme pencils, and the object itself is referred to an infinite distance, or to the concave surface of the heavens.

372. *Prop.* When a convex lens is placed between the eye and any object, so as to have the object at a distance from the lens equal to its focal length, it will be distinctly seen by an eye capable of converging parallel rays, and will appear enlarged beyond its natural size.

Let P Q be the object, C the lens, and E the centre of the eye. Since the object is in the focus of the lens, the rays of a pencil diverging from any point P in it, will emerge parallel to P C, and to each other; they will, therefore, after refraction in the eye, be brought to converge on the retina to a point p, such that E p is parallel to P C. Similarly, rays from Q will, after refraction through the lens and eye, converge to q; such that E q is parallel to Q C. Thus, a distinct image will be formed at $p\,q$ on the retina, and the apparent angular magnitude of the object seen through the lens will be the angle q E p. Now this is equal to P C Q, or the angle subtended by the object at the centre of the lens, and is, therefore, greater than P E Q, or that subtended by it at the centre of the eye, because the lens is between the eye and object. Fig. 73.

373. Hence, the nearer the eye is to the lens, the less will be the difference between the apparent magnitudes of the object, as seen with and without the lens interposed. But if the lens be of shorter focus than the least distance at which the eye can see distinctly, there will be this essential difference between vision with and without the lens, that in the former case the object is seen distinctly, and well-defined; while in the latter, or with the naked eye, it will be indistinct and confused, and the more so the nearer it is brought.

374. Hence, by the use of a convex lens of short focus, objects may be seen distinct, and magnified to any extent we please: for let L be the power, or reciprocal focal length of the lens, and D the greatest proximity of the object to the centre of the eye at which it can be seen distinctly without a lens. Then we shall have L : D : : angle P E q : angle subtended by the object at the proximity D; and, therefore, : : apparent linear magnitude of object seen through the lens : apparent linear magnitude at proximity D, with the naked eye. Therefore $\frac{\mathrm{L}}{\mathrm{D}}$ is the ratio of these magnitudes, or, as it is called, the *magnifying power* of the lens, beyond that of the naked eye, at its greatest proximity. By a convex lens of short focus objects are magnified. Magnifying power.

375. *Corol.* D being given, the magnifying power is as L, or as $(\mu - 1)\,(\mathrm{R}' - \mathrm{R}'')$. This explains the use of the word power in the foregoing sections. Whatever we have demonstrated of the powers of lenses in the foregoing pages, is true of *magnifying powers*. Thus the sum of the magnifying powers of two convex lenses is the magnifying power of the two combined. If one be concave, its magnifying power is to be regarded as negative, and instead of their sum we must take their difference. Magnifying power of a system of lenses.

376. *Prop.* To express, generally, the *visual angle* under which a small object placed at any distance from a lens, and seen by an eye any how situated, appears, supposing it seen distinctly.

Let P Q, fig. 74, 75, 76, 77, be the object, E the lens, O the eye, and $p\,q$ the image. Put $\frac{1}{\mathrm{E\,Q}} = \mathrm{D}$, $\frac{1}{\mathrm{E}\,q} = f$; $\frac{1}{\mathrm{E\,O}} = e$; e being reckoned in the same direction from the centre of the lens that D and f are. Then the visual angle under which the image is seen is q O p, and we have, therefore, visual angle $(= \mathrm{A}) = \frac{q\,p}{\mathrm{O}\,q} = \frac{q\,p}{\mathrm{O\,E} - \mathrm{E}\,q}$. But, $q\,p = \mathrm{Q\,P} \, . \, \frac{\mathrm{E}\,q}{\mathrm{E\,Q}} = \mathrm{Q\,P} \, . \, \frac{\mathrm{D}}{f} = \mathrm{O} \, . \, \frac{\mathrm{D}}{f}$ putting O for Q P the linear magnitude of the object; and, moreover, $\mathrm{O\,E} - \mathrm{E}\,q = \frac{1}{e} - \frac{1}{f} = \frac{f - e}{f\,e}$, therefore we have, Fig. 74, 75, 76, 77. Visual angle. Vision through convex lenses.

$$\mathrm{A} = \mathrm{O} \, . \, \frac{\mathrm{D}}{f} \, . \, \frac{e\,f}{f - e} = \mathrm{O} \, . \, \frac{e\,\mathrm{D}}{\mathrm{L} + \mathrm{D} - e}$$

when L, as all along, represents the power of the lens. Now O . D is the visual angle of the object, as seen from the centre of the lens; therefore, putting O . D, or $\frac{\mathrm{Q\,P}}{\mathrm{Q\,E}} = (\mathrm{A})$ we get

$$\mathrm{A} = (\mathrm{A}) \, . \, \frac{e}{\mathrm{L} + \mathrm{D} - e}. \qquad (a)$$

377. Through concave. In concave lenses, the images of distant objects are formed erect, and on the same side of the lens with the object. If, therefore, such a lens be held between the eye and distant objects at a sufficient distance from the eye for distinct vision, the objects will be seen *erect*, and *diminished* in magnitude. In this case, e is positive, and L and D both negative; therefore $L + D - e$ is a negative quantity, greater (without regard to the sign) than e, and, consequently, A is negative, and less than (A).

378. In reflectors. In reflectors, $f = 2R - D$, and, therefore,

$$A = (A) \cdot \frac{e}{2R - D - e}. \qquad (b)$$

In a convex reflector, e is necessarily negative, at least if the mirror be made of metal, because the eye must be on the side of the surface towards the incident light; and, therefore, $2R - e$ is positive, and $\frac{e}{2R - D - e}$ will be greater or less than unity, according to the value of $2R - D - e$. In concave reflectors, R is negative, and e is also negative for the same reason as in concave; therefore the sign and magnitude of A in this, as well as the former case, may vary indefinitely, according to the place of the eye, the image, and the object. The varieties of these cases are represented in fig. 78 and 79.

379. General principles of telescopes. If the image, instead of being seen directly by the naked eye, be seen through the medium of another lens or reflector, so placed as to cause the pencils diverging primarily from each point of the object, to emerge finally, either exactly parallel, or within such limits of convergence or divergence as the eye can accommodate itself to, the object will be seen distinctly, and either larger or smaller than it would be seen by the unassisted eye, according to the magnitude of the image, and the power of the lens or reflector used to view it. This is the principle of all telescopes and microscopes. As most eyes can see with parallel rays, they are so constructed as to make parallel pencils emerge parallel; and a mechanical adjustment allows such a quantity of motion of the lenses or reflectors with respect to each other, as to give the rays a sufficient degree of convergence or divergence as may be required.

380. Astronomical telescope. In the common refracting, or, as it is sometimes called, the astronomical telescope, the image is first formed by a convex lens, and is viewed through a convex lens, placed at a distance from the other nearly equal to the sum of their focal lengths. The lens which forms the image is called the *object-glass*, and that through which it is viewed, the *eye-glass* of the telescope. If the latter be concave, the telescope is said to be of the Galilæan construction, such having been the original arrangement of Galilæo's instruments. The situation of the lenses, and the course of the rays in these two constructions, are represented in fig. 80 and 81. Fig. 80, 81.

381. In the former construction, let P Q be the object. Draw Q O G through the centres of the object and eye-glass, and this line will be the axis of the telescope. From R any point in the object draw P O p through the centre O of the object-glass, and meeting $p\,q$, a line through q, the focus of the point Q, perpendicular to the axis in p, then will $p\,q$ be the image of P Q. Let P A, P B be the extreme rays of the pencil diverging from P, and incident on the object-glass, and they will be refracted to and cross at p. Hence, unless the diameter of the eye-glass b G a be such, that the ray A p a shall be received on it, the point p will be seen less illuminated than the point p in the centre of the object, and if it be so small that the line B p produced does not meet it, then none of the rays from P can reach the eye at all. Thus, the ***field of view***, Field of view. or angular dimensions of the object seen, is limited by the aperture of the eye-glass. To find its extent, then, join B b, A a, opposite extremities of the object and eye-glass, meeting the image in r and p, and the axis in X, then $r\,p$ is the whole extent of the image which is seen at all, and the angle p O r, which is equal to P O R, is the angular extent of the field of view. Now we have $AB : ab :: OX : GX$, and, therefore, $AB + ab : AB :: OG : OX$, whence we get $OX = \frac{AB}{AB + ab} \cdot OG$; $GX = \frac{ab}{AB + ab} \cdot OG$. But we have, moreover, $Xq = Oq - OX$; $pr = ab \cdot \frac{Xq}{GX}$, and angle $rOp = \frac{rp}{Oq}$. To express this algebraically, put

Diameter of object-glass $= \alpha$; Power of object-glass $= L$
Diameter of eye-glass $= \beta$; Power of eye-glass $= l$.

Then

$$\left.\begin{aligned} OX &= \frac{\alpha}{\alpha + \beta}\left(\frac{1}{L} + \frac{1}{l}\right); \quad GX = \frac{\beta}{\alpha + \beta}\left(\frac{1}{L} + \frac{1}{l}\right) \\ QX &= \frac{1}{\alpha + \beta}\left(\frac{\beta}{L} - \frac{\alpha}{l}\right); \text{ and } pr = \frac{\beta l - \alpha L}{L + l}; \end{aligned}\right\}, \qquad (c)$$

This last is the linear magnitude of the visible portion of the image; and it is, as we see, symmetrical both with respect to the eye-glass and object-glass.

382. Now from this it is easy to deduce both the field of view and magnifying power of the telescope; for the former is equal to the angle subtended by $p\,r$, at the centre of the object-glass, and the latter is obtained from the former, when the angle r G p subtended at the centre of the eye-glass is obtained. But we have

$$\left.\begin{aligned} r\,\mathrm{O}\,p = \mathrm{L}\,.\,\frac{\beta l - a\mathrm{L}}{\mathrm{L}+l}; \qquad r\,\mathrm{G}\,p = l\,.\,\frac{\beta l \quad a\mathrm{L}}{\mathrm{L}+l} \\ \text{therefore} \qquad \text{magnifying power} = \frac{r\,\mathrm{G}\,p}{r\,\mathrm{O}\,p} = \frac{l}{\mathrm{L}} \end{aligned}\right\}. \qquad (d)$$

Formulæ for field of view and magnifying power.

Hence we see, that the greater the power of the eye-glass is, compared with that of the object-glass, the greater the magnifying power of the telescope; or, in other words, the greater the focal length of the object glass compared with that of the eye-glass.

383. Distance of eye. The pencils of rays after refraction at the eye-glass will emerge parallel, and therefore proper for distinct vision to an eye properly placed to receive them. Now the eye will receive both the extreme rays $b\,\mathrm{R}'$ and $a\,\mathrm{P}'$ of the pencils diverging from r and p, if it be placed at their point of concourse E; but since $b\,\mathrm{E}$ is parallel to $r\,\mathrm{G}$, and $a\,\mathrm{E}$ to $p\,\mathrm{G}$, we have

$$\mathrm{G\,E} = \mathrm{G}\,q \times \frac{a\,b}{p\,r}, \qquad \text{or } \mathrm{G\,E} = \frac{\beta(\mathrm{L}+l)}{\beta l - a\mathrm{L}}. \qquad (e)$$

384. If the eye be placed nearer to, or farther off from, the eye-glass than this distance, it will not receive the extreme rays, and the *field of view*, or visible area of the object, will be lessened. In the construction of convex single eye-pieces, therefore, care must be taken to prolong the tube which carries them, (as in the figure,) so that when the eye is applied close to its end, it shall still be at this precise distance from the glass.

385. Inversion of telescopes. If the telescope be inverted, and the eye applied behind the object-glass, it is evident that it will remain a telescope, but its magnifying power will be changed to $\frac{\mathrm{L}}{l}$; so that, if it magnified before, it will diminish objects now, and the field of view will be proportionally increased. In this way, beautiful miniature pictures of distant objects may be seen.

386. Adjustments. If the telescope, instead of being turned on objects so distant as that the pencils flowing from them may be regarded as parallel, be directed to near objects, the distance between the object-glass and eye-glass must be lengthened so as to bring the image exactly into the focus of the latter. To accomplish this, the eye-glass is generally set in a sliding tube movable by a rack-work, or by hand. The same mechanism serves also to adjust the telescope for long or short-sighted persons. The former require parallel or slightly divergent rays, the latter very divergent; and to obtain the necessary divergence for the latter, the eye-glass must be brought nearer the object-glass.

387. Galilæan telescope. The same theory and formulæ apply to the second, or Galilæan, construction, only recollecting that in this case L, the power of the eye-glass, is negative. In this case, therefore, the value of G E is negative, or the eye should be placed between the object-glass and eye-glass; but, as that is incompatible with the other conditions, in order to get as great a field of view as possible, the eye must be brought as near to its proper place as possible, and therefore close to the eye-glass.

388. In the astronomical telescope objects are seen inverted, in the Galilæan, erect; for, in the former, the rays from the extremities of the object have crossed before entering the eye, in the latter, not.

389. Microscopes. If the object be brought nearer the object-glass, the magnifying power is increased; because in this case (calling D the proximity of the object) $\frac{l}{\mathrm{L}-\mathrm{D}}$ expresses the magnifying power, as is easily seen from what has been said Art. 382. Thus a telescope used for viewing very near objects becomes a *microscope*. The ordinary construction of the compound microscope is nothing more than that of the astronomical telescope modified for the use it is intended for. The object-glass has in this instrument a much greater power than the eye-glass, so that, when employed for viewing distant objects, it acts as a telescope inverted, and requires to be greatly shortened. But for near objects, as D increases, $l - \mathrm{D}$ diminishes, and the fraction $\frac{l}{l-\mathrm{D}}$ may be increased to any amount, by bringing the object nearer to the object-glass, and at the same time lengthening the interval between the lenses, which is expressed by $\frac{1}{\mathrm{L}-\mathrm{D}} + \frac{1}{l}$. But as this requires two operations, it is usual to leave the latter distance unaltered, and vary, by a screw or rack-work, only the former. Fig. 82 is a section of such an instrument. Fig. 82. It is, however, convenient to have the power of lengthening and shortening the distance between the glasses, as by this means any magnifying power between the limits corresponding to the extreme distances may be obtained; and if a series of object-glasses be so selected, that the greatest power attainable by one within the limits of the adjustment in question, shall just surpass the least obtainable by the next, and so on, we may command any power we please. Such a series is usually comprised in a small revolving plate containing cells, each of which can be brought in succession into the axis of the microscope by a simple mechanism.

390. Reflecting telescope. In the reflecting telescope, of the most simple construction, the image is formed by a concave mirror, and viewed by a convex or concave eye-glass, as in refracting telescopes; but since the head of the observer would intercept the whole of the incident light in small telescopes, and a great part of it in large ones, the axis of the reflector itself is turned a little obliquely, so as to throw the image aside, by which it can be viewed with little or no loss of light. The inconvenience of this is a little distortion of the image, caused by the obliquity of the rays;

but as such telescopes are only used of a great size, and for the purpose of viewing very faint celestial objects, in which the light diffused by aberration is insensible, little or no inconvenience is found to arise from this cause. **Simplest, or Herschelian construction.** Such is the construction of the telescopes used by Sir William Herschel in his sweeps of the heavens.

391. **Newtonian construction.** To obviate the inconvenience of the stoppage of rays by the head, Newton, the inventor of reflecting telescopes, employed a small mirror, placed obliquely, as in fig. 83, opposite the centre of the large one. Thus parallel rays P A, P B, emanating from a point in the axis of the telescope, are received, before their meeting, on a plane mirror C D inclined at 45° to the axis, and thence reflected through a tube projecting from the side of the telescope to the lens G, and by it refracted to the eye E. It is manifest, that if the image formed by the mirror A B behind C D be regarded as an object, an image equal and similar to it (Art. 335) will be formed at F, at an equal distance from the plane mirror; and this image will be seen through the glass G, just as if it were formed by an object-glass of the same focal length placed in the prolongation of the axis of the eye-tube, beyond the small mirror, (supposed away.) Hence the same propositions and formulæ will hold good in the Newtonian telescope, as in the astronomical and Galilæan, for the magnifying power, field of view, and position of the eye, substituting only 2 R for L, and 2 R − D for L − D, and recollecting that R is negative, as the mirror has its concavity turned towards the light.

392. **Gregorian telescope. Fig. 84.** The Gregorian telescope, instead of a small plain mirror turned obliquely, has a small convex mirror with its concavity turned towards that of the large one, as in fig. 84; but instead of being placed at a distance from the large one equal to the sum of the focal lengths, the distance is somewhat greater; hence the image *p q*, formed in the focus of the great mirror, being at a distance from the vertex of the small one greater than its focal length, another image is formed at a distance, viz. at or near the surface of the great mirror, at *r s*. In the centre of the large mirror there is a hole which lets pass the rays to an eye-lens *g*. The adjustment to parallel or diverging rays, or for imperfect eyes, is performed by an alteration of the distance between the mirrors made by a screw.

393. **Cassegrainian.** The Cassegrainian construction differs in no respect from the Gregorian, except that the small mirror is convex and receives the rays before their convergence to form an image. The magnitude of the field, the distance of the eye and of the mirrors from each other, are easily expressed in these constructions; the latter being derived from the former by a mere change of sign in the curvature of the small mirror. Let then R′ and R″ be the curvatures of the two mirrors, then in the Gregorian telescope R′ is negative and R″ positive; and if we put *t* for the distance between their surfaces, (*t* being negative, because the second reflecting surface lies towards the incident light) we shall have for an object whose proximity is D

$$D' = D; \qquad f' = 2\,R' - D' = 2\,R' - D; \qquad f'' = 2\,R'' - D''; \qquad D'' - \frac{f'}{1 - f'\,t'},$$

adopting the formulæ and notation of Art. 251. Now these give, by substitution,

$$D'' = \frac{2\,R' - D}{1 - t\,(2\,R' - D)}; \qquad f'' = 2\,R'' - \frac{2\,R' - D}{1 - t\,(2\,R' - D)} =$$

$$= \frac{2\,R'' - 2\,R' + D - 2\,t\,(2\,R' - D)\,.\,R''}{1 - t\,(2\,R' - D)}. \qquad (f)$$

This is the reciprocal distance of the second image from the second reflecting surface. If we wish that the image to be viewed by the eye-lens should fall *just* on the surface of the large mirror, we have only to put $f'' = \frac{1}{-t}$ (because f'' is positive, and t negative.) For parallel rays this gives

$$R'\,R''\,.\,t^2 + (4\,R' - 2\,R'')\,t - 1 = o; \qquad (g)$$

whence *t* may be found when R′ and R″ are given, or *vice versâ*.

394. The description of other optical instruments, and of the more refined construction of telescopes, &c. must be deferred till we are farther advanced in our account of the physical properties of light, and especially of the different refrangibility of its rays and their colours, which will form the object of the next part.

1. A beam of white light consists of a great and almost infinite variety of rays differing from each other in colour and refrangibility.

Rays of light differ in refrangibility.

For the ray S F from any one point of the sun's disc, which if received immediately on the screen would have occupied only a single point on it, or (supposing the hole in the screen to have a sensible diameter) only a space equal to its area, is dilated into a line V R of considerable length, every point of which (speaking loosely) is illuminated. Now the rays which go to V must necessarily have been more refracted than those which go to R, which can only have been in virtue of a peculiar quality in the rays themselves, since the refracting medium is the same for all.

401. 2. White light may be *decomposed*, *analyzed*, or separated into its elementary coloured rays by refraction. The act of such separation is called the *dispersion* of the coloured rays.

402. 3. Each elementary ray once separated and insulated from the rest, is incapable of further decomposition or analysis by the same means. For we may place a third, and a fourth, prism in the way of the twice refracted ray *g x*, and refract it in any way, or in any plane; it remains undispersed, and preserves its colour quite unaltered.

403. 4. The dispersion of the coloured rays takes place in the plane of the refraction; for it is found that the spectrum V R is always elongated in this plane. Its breadth is found, on the other hand, by measurement, to be precisely the same as that of the white image D, (fig. 86,) of the sun, received on a screen at a distance O D from the hole, equal to O F + F G + G R, the whole course of the refracted light, which shows that the beam has undergone no contraction or dilation by the effect of refraction in a plane perpendicular to the plane of refraction.

404. Index of refraction regarded as variable.

To explain all the phenomena of the colours produced by prismatic dispersion, or of the *prismatic* colours, as they are called, we need only suppose, with Newton, that each particular ray of light, in undergoing refraction at the surface of a given medium, has the sine of its angle of incidence to that of refraction in a constant ratio, so long as the medium and the ray are the same; but that this ratio varies not only, as we have hitherto all along assumed, with the nature of the medium, but also with that of the ray. In other words, that there are as many distinct species, or at least varieties of light, as there are distinct illuminated points in the spectrum into which a single ray of white light is dispersed. This amounts to regarding the quantity μ, for any medium, not as one and invariable, but as susceptible of all degrees of magnitude between certain limits: one, the least of which, corresponds to the extreme, or least refracted red ray; the other, the greatest value of μ, to the extreme or most refracted violet. Each of these varieties separately conforms to the laws of reflexion and refraction we have already laid down. As in Geometry we may regard a whole family of curves as comprehended under one equation, by the variation of a constant parameter; so in Optics we may include under one analysis all the doctrine of the reflexions, refractions, and other modifications of a ray of white or compound light, by regarding the refractive index μ as a variable parameter.

405. To apply this, for instance, to the experiment of the prism just related: A single ray of white light being supposed incident on the first surface, must be regarded as consisting of an infinite number of coincident rays, of all possible degrees of refrangibility between certain limits, any one of which may be indifferently expressed by the refractive index μ. Supposing the prism placed so as to receive the incident ray perpendicularly on one surface, then the deviation will be given by the equation

$$\mu \,.\, \sin \mathrm{I} = \sin (\mathrm{I} + \mathrm{D})$$

I being the refracting angle of the prism. D therefore is a function of μ, and if μ vary by the infinitely small increment $\delta \mu$, *i. e.* if we pass from any one ray in the spectrum to the consecutive ray, D will vary by δ D, and the relation between these simultaneous changes will be given by the equation resulting from the differentiation of the above with the characteristic δ: thus we get

$$\delta \mu \,.\, \sin \mathrm{I} = \delta \mathrm{D} \,.\, \cos (\mathrm{I} + \mathrm{D}); \qquad \delta \mathrm{D} = \delta \mu \,.\, \frac{\sin \mathrm{I}}{\cos (\mathrm{I} + \mathrm{D})}. \qquad (a)$$

It is evident, then, that as μ varies, D also varies; and, therefore, that no two of the refracted and coloured rays [illegible] will coincide, but will be spread over an angle, in the plane of refraction, the greater, the greater is the total [illegible] variation of μ from one extreme to the other.

406. Analysis and synthesis of white light. Fig. 87.

In order to justify the term *analysis*, or *decomposition*, as applied to the separation of a beam of white light [illegible] into coloured rays, we must show by experiment that white light may be again produced by the *synthesis* of these [illegible] elementary rays. The experiment is easy. Take two prisms A B C, *a b c* of the same medium, and having [illegible] equal refracting angles, and lay them very near together, having their edges turned opposite ways, as in fig. 87. [illegible] With this disposition, a parallel beam of white light intromitted into the face A C of the first prism, will emerge [illegible] from the face *b c* of the last, undeviated, and colourless, as if no prisms were in the way. Now the dispersion [illegible] having been fully completed by the prism A B C, the rays in passing through the thin lamina of air B C *a c* must [illegible] have existed in their coloured and independent state, and been dispersed in their directions; but being refracted [illegible] by the second prism so as to emerge parallel, the colour is destroyed by the mixture and confusion of the rays. [illegible]

Fig. 88.

To see more clearly how this takes place in fig. 88, let S R and S V be two parallel white rays, incident on the [illegible] first prism, and separated by refraction; the former into the coloured pencil R *c v*, the latter into a pencil exactly [illegible] similar to V *r c*. Let R *c* be the *least* refracted ray of the former pencil, and V *c* the *most* refracted of the [illegible] latter. These, of course, must meet; let them meet in *c*, and precisely at *c* apply the vertex of the second [illegible] prism, having its side *c a* parallel to C B, but its edge turned in the opposite direction; then will the rays R *c* and V *c*, each for itself, and independent of the other, be refracted so as to emerge parallel to its original directio[illegible]

S R, S V, and the emergent rays will therefore be coincident and superimposed on each other as cs. Thus the emergent ray cs will contain an extreme red and an extreme violet ray. But it will also contain every intermediate variety; for draw cf anywhere between c R and c V. Then, since the angle which cf makes with the surface B C is greater than that made by the extreme violet ray C B, but less than that made by the extreme red, there must exist some value of μ intermediate between its extreme values, which will give a deviation equal to the angle between cf and S Y parallel to S R. Consequently, if S Y be a white ray, separated into the pencil $Y v' r'$ by refraction, the coloured ray $Y f c$ of that particular refrangibility will fall on c, and be refracted along cs. Every point then of the surface gfh will send to c a ray of different refrangibility, comprehending all the values of μ from the greatest to the least. Thus all the coloured elements, though all belonging originally to different white rays, will, after the second refraction, coincide in the ray cs, and experience proves that so reunited they form white light. White light, then, is re-composed when all the coloured elements, even though originally belonging to separate white rays, are united in place and direction.

407. In the reflexion of light, regarded as a case of refraction, μ has a specific numerical value, and cannot vary without subverting the fundamental law of reflexion. Thus, there is no dispersion into colours produced by reflexion, because all the coloured rays after reflexion pursue one and the same course. There is one exception to this, more apparent than real, when light is reflected from the base of a prism internally, of which more hereafter.

408. Synthesis of white light by a lens.

The recomposition of white from coloured light may be otherwise shown, by passing a small circular beam of solar light through a prism A B C, (fig. 89,) and receiving the dispersed beam on a lens E D at some distance. If a white screen be held behind the lens, and removed to a proper distance, the whole spectrum will be reunited in a spot of white light. The way in which this happens will be evident by considering the figure, in which T E and T D represent the parallel pencils of rays of any two colours (red and violet, for instance) into which the incident white beam S T is dispersed. These will be collected after refraction, each in its own proper focus; the former at F, the latter at G; after which each pencil diverges again, the former in the cone F H, the latter in G H. If the screen then be held at H, each of these pencils will paint on it a circle of its own colour, and so of course will all the intermediate ones; but these circles all coinciding, the circle H will contain all the rays of the spectrum confounded together, and it is found (with the exception of a trifling coloured fringe about the edges, arising from a slight overlapping of the several coloured images) to be of a pure whiteness.

409. All the rays necessary to produce white.

That the reunion of *all* the coloured rays is necessary to produce whiteness, may be shown by intercepting a portion of the spectrum before it falls on the lens. Thus, if the violet be intercepted, the white will acquire a tinge of yellow; if the blue and green be successively stopped, this yellow tinge will grow more and more ruddy, and pass through orange to scarlet and blood red. If, on the other hand, the red end of the spectrum be stopped, and more and more of the less refrangible portion thus successively abstracted from the beam, the white will pass first into pale and then to vivid green, blue-green, blue, and finally into violet. If the middle portion of the spectrum be intercepted, the remaining rays, concentrated, produce various shades of purple, crimson, or plum-colour, according to the portion by which it is thus rendered deficient from white light; and by varying the intercepted rays, any variety of colours may be produced; *nor is there any shade of colour in nature which may not thus be exactly imitated, with a brilliancy and richness surpassing that of any artificial colouring.*

All natural colours imitable by combinations of the prismatic.

Now, if we consider that all these shades are produced on white paper, which receives and reflects to our eyes whatever light happens to fall on it; and that the same paper placed successively in the red, green, and blue portion of the spectrum, will appear indifferently red, or green, or blue, we are naturally enough led to conclude, that

410. Colours not inherent in bodies.

The colours of natural bodies are not qualities inherent in the bodies themselves, by which they immediately affect our sense, but are mere consequences of that peculiar disposition of the particles of each body, by which it is enabled more copiously to reflect the rays of one particular colour, and to transmit, or stifle, or, as it is called in Optics, absorb the others.

411. Proved by experiment

Such is the Newtonian doctrine of the origin of colours. Every phenomenon of optics conspires to prove its justice. Perhaps the most direct and satisfactory proof of it is to be found in the simple fact, that every body, indifferently, whatever be its colour in white light, when exposed in the prismatic spectrum, appears of the colour appropriate to that part of the spectrum in which it is placed; but that its tint is incomparably more vivid and full when laid in a ray of a tint analogous to its hue in white light, than in any other. For example, vermillion placed in the red rays appears of the most vivid red; in the orange, orange; in the yellow, yellow, but less bright. In the green rays, it is green; but from the great inaptitude of vermillion to reflect green light, it appears dark and dull; still more so in the blue; and in the indigo and violet it is almost completely black. On the other hand, a piece of dark blue paper, or Prussian blue, in the indigo rays has an extraordinary richness and depth of blue colour. In the green its hue is green, but much less intense; while in the red rays it is almost entirely black. Such are the phenomena of pure and intense colours; but bodies of mixed tints, as pink or yellow paper, or any of the lighter shades of blue, green, brown, &c., when placed in any of the prismatic rays, reflect them in abundance, and appear, for the time, of the colour of the ray in which they are placed.

412. Precautions to insure the perfect homogeneity of a ray. Fig. 89.

Refraction by a prism affords us the means of separating a ray of white light into the rays of different refrangibility of which it consists, or of analyzing it. But to make the analysis complete, and to insulate a ray of any particular refrangibility in a state of perfect purity, several precautions are required, the chief of which are as follows: 1st. The beam of light to be analyzed must be very small, as nearly as possible approaching to a mathematical ray; for if A B, ab be a beam of parallel rays of any sensible breadth (fig. 89) incident on the prism P, the extreme rays A B, ab will each be separated by refraction into spectra G B H and gbh: B G, bg being the violet, and B H, bh the red rays of each respectively; and since A B, ab are parallel, therefore C G

1st. Smallness of the incident pencil.

and $c\,g$ will be so, and also D H and $d\,h$. Hence the red ray D H from B will intersect the violet $c\,g$ from b, in some point F behind the prism; and a screen E F f placed at F will have the point F illuminated by a red ray from B, and a violet one from b; and therefore (as is easily seen) by all the rays intermediate between the red and violet, from points between B and b. F therefore will be white. If the screen be placed nearer the prism than F, as at K L $k\,l$, it is clear that from any point between L and k lines drawn parallel to K C, D L, to any intermediate direction, will fall between C and c, D and d, &c., respectively; and therefore that every point between L and k will receive from some point or other of the surface C d of the prism a ray of each colour, and will therefore be white. Again, any point as x between k and l can receive no violet ray, nor any ray of the spectrum whose angle of deviation is greater than $180° - a\,b\,x$; for such ray to reach x must come from a part of the prism below b, which is contrary to the supposition of a limited beam A B, $a\,b$; but all rays whose angle of deviation is less than $180° - a\,b\,x$, will reach x from some part or other of the surface B D. Hence the colour of the portion $k\,l$ of the image on the screen will be white at k, pure red at l, and intermediate between white and red, or a mixture of the *least* refrangible rays of the spectrum at any intermediate point; and, in the same manner, the portion K L will be white at L, violet at K, and at any intermediate point will have a colour formed by a mixture of a greater or less portion of the more refrangible end of the spectrum. If the screen be removed beyond F, as into the situation G g H h, the white portion will disappear, no point between g and H being capable of receiving any ray whose angle of deviation is between $180° - a\,b\,g$ and $180 - a\,b$ H. We may regard the whole image G h as consisting of an infinite number of spectra formed by every elementary ray of which the beam A B $a\,b$ is composed, overlapping each other, so that the end of each in succession projects beyond that of the foregoing. The fewer, therefore, there are of these overlapping spectra, or the smaller the breadth of the incident beam, the less will be the mixture of rays so arising, and the purer the colours. Removal of the screen to a greater distance from the prism, evidently produces the same effect as diminution of the size of the beam; for while each colour occupies constantly the same space on the screen (for G g = K k) the whole spectrum is diffused over a larger space as the screen is removed, by the divergence of its component rays of different colours, and therefore the individual colours must of necessity be continually more and more separated from each other.

413. 2nd. Small angular divergence of the pencil. Fig. 90.

2ndly. Another source of confusion and want of perfect homogeneity in the colours of the spectrum is the angular diameter of the sun or other luminary, even when the aperture through which the beam is admitted is ever so much diminished. For let S T (fig. 90) be the sun, whose rays are admitted to the prism A B C through a very small hole O in a screen placed close to it. The beam will be dilated by refraction into the spectrum $v\,r$. Now, if we consider only the rays of one particular kind, as the red, and regard all the rest as suppressed, it is clear that a red image r of the sun will be formed by them alone on the screen; the rays from every point of the sun's disc crossing at O, and pursuing (after refraction) different courses. If the prism be placed in its situation of minimum deviation, which at present we will suppose, this image will be a circle, and it and the sun will subtend equal angles at O. In like manner, the violet rays (considered apart from the red) will form a circular violet image of the sun, at v, by reason of their greater refrangibility; and every species of ray, of intermediate refrangibility, will form, in like manner, a circular image between r and v. The constitution of the spectrum so arising will therefore be as in fig. 91, a, being an assemblage of images of every possible refrangibility superposed on and overlapping each other. Now, if we diminish the angular diameter of the sun or luminary, each of these images will be proportionally diminished in size; but their number, and the whole extent over which they are spread, will remain the same. They will therefore overlap less and less, (as in fig. 91, b, c;) and if the luminary be conceived reduced to a mere point (as a star) the spectrum will consist of a line d composed of an infinite number of mathematical points, each of a perfectly pure homogeneous light.

Fig. 91.

414. Experimental methods of obtaining homogeneous prismatic rays. Fig. 7.

There are several ways by which the angular diameter, or the degree of divergence of the incident beam may be diminished. Thus, first, we may admit a sunbeam through a small hole, as A, in a screen, and receive the divergent cone of rays behind it on another screen B, (fig. 7,) at a considerable distance, having another small hole B to let pass, not the whole, but only a small portion of the sun's image. The beam B C, so transmitted, will manifestly have a degree of divergence less than that of the beam immediately transmitted from A in the proportion of the diameter of the aperture B to the diameter of the sun's image on the screen B.

415. Fig. 92.

Another and much more commodious method is to substitute for the sun its image formed in the focus of a convex lens of short focus. This image is of very small dimensions, its diameter being equal to focal length of the lens × sine of sun's angular diameter, (or sine of 30′, which is about one 114th part of radius,) so that a lens of an inch focus concentrates all the rays which fall on it within a circle of about the 114th of an inch in diameter, which, for this purpose, may be regarded as a physical point. The disposition of the apparatus is as represented in fig. 92. The rays converged by the lens L to F, afterwards diverge as if they emanated from an intensely bright luminous point placed at F, and a screen with a small aperture O being placed at a distance from it, and close behind it the prism A B C, the spectrum $r\,v$ may be received on a screen again placed at a considerable distance behind the prism, each of whose points will be illuminated by rays of a very high degree of purity and homogeneity, and by diminishing the focal length of the lens, and the aperture O, and increasing the distance F O, or O r, this may be carried to any extent we please. It should, however, be remarked, that the intensity of the purified ray, and the quantity of homogeneous light so obtained, are diminished in the same ratio as the purity of the ray is increased.

416. Fig. 93.

A third method of obtaining a homogeneous beam is to repeat the process of analysis on a ray as nearly pure as can be conveniently obtained by refraction through a single prism. Thus, in fig. 93, V R, the spectrum formed by a first refraction at the prism A, is received on a screen which intercepts the whole of it, except that particular colour we wish to insulate and purify, which is allowed to pass through an aperture M N; behind this is placed another prism B, so as to refract this beam a second time. If then the portion

First method of exhibiting the fixed lines.

which the rays diverge, as from a fine luminous line, in the manner described in Art. 415 for a lens. If now the eye be applied close behind the prism, the line will be seen dilated into a broad coloured band, consisting of the prismatic colours in their order; and if the prism be good, and carefully placed in its situation of minimum deviation, and of sufficiently large refracting angle to give a broad spectrum, some of the more remarkable of the fixed lines will be seen arranged parallel to the edges of the spectrum, especially the lines D and F, the former of which appears, in this way of viewing it, to form a separation between the red and the yellow. If the light of the sun be too bright, so as to dazzle the eye, any narrow line of common daylight (as the slit between two nearly closed window-shutters) may be substituted. This was the mode in which the fixed lines were first discovered by Dr. Wollaston.

422. Second method.

But it is difficult and requires acute sight to perceive, in this manner, any but the most conspicuous lines. The reason is, their very small angular breadth; which, in the largest of them, can scarcely, under any circumstances, exceed half a minute, and in the smaller not more than a few seconds. They require, therefore, to be magnified. This may be done by a telescope interposed between the eye and the prism, in the manner represented in fig. 95, in which L l is the line of light, from which rays, diverging in all directions, fall on the prism A B C, are refracted by it, and after refraction are received on the object-glass D of the telescope. This object-glass, it should be observed, must be of that kind denominated *achromatic*, to be presently described, (see Index,) and of which it need only be here said, that it is so constructed as to be capable of bringing rays of all colours to foci at one and the same distance from the glass. Now, if we consider only rays of any one degree of refrangibility (the extreme red, for instance) the pencils diverging from every point of L l will, after refraction at the two surfaces of the prism, diverge from corresponding points of an image $L' l'$ situated in the direction from the base towards the vertex of the prism. Rays of any greater refrangibility will, after refraction at the prism, diverge from a linear image $L'' l''$ parallel to $L' l'$, but farther from the original line L l. Thus the white line L l will, after refraction at the prism, have for its image the coloured rectangle $L' L'' l' l''$, which will be viewed through the telescope as if it were a real object. Now every vertical line of this parallelogram will form in the focus of the object-glass a corresponding vertical image of its own colour; and the object-glass being achromatic, all these images are equidistant from it, so that the whole image of the parallelogram $L' l''$ will be a similar coloured parallelogram, having its plane perpendicular to the axis of the telescope. This will be viewed as a real object through the eye-glass, and the spectrum will thus be magnified as any other object would be, according to the power of the telescope, (Art. 382.) With this disposition of the apparatus (which is that employed by Fraunhofer) the fixed lines are beautifully exhibited, and (if the prism be perfect) may be magnified to any extent. The slightest defect of homogeneity in the prism, however, as may be readily imagined, is fatal. With glass prisms of our manufacture it would be quite useless to attempt the experiment; and those who would repeat it in this country should employ prisms of highly refractive liquids, enclosed in hollow prisms of good plate glass. The eye-pieces of telescopes, not being usually achromatic, a slight change of focus is still required, when the lines in the red and violet portions of the spectrum are to be viewed. This (if an inconvenience) might be obviated by the use of an achromatic eye-piece.

Fig. 95.

423. Third method.

That an actual image of the spectrum, with its fixed lines, is really formed in the focus of the object-glass, as described, may be easily shown, by dismounting the telescope, and receiving the rays refracted by the object-glass on a screen in its focus. This, indeed, affords a peculiarly elegant and satisfactory mode of exhibiting the phenomena to several persons at once. An achromatic object-glass of considerable focal length (6 feet, for instance) should be placed at about twice its focal length from the line of light, and (the prism being placed immediately before the glass) the image will be formed at about the same distance, 12 feet behind it, ($f = L + D$; $L = \frac{1}{6}$; $D = -\frac{1}{12}$; $f = \frac{1}{6} - \frac{1}{12} = +\frac{1}{12}$) and being received on a screen of white paper or emeried glass may be examined at leisure, and the distances of the lines from each other, &c. measured on a scale. But by far the best methods of performing these measurements are those practised by Fraunhofer, viz. the adaptation of a micrometer to the eye-end of the telescope, (see *Micrometer*, in a subsequent part of this Article,) for ascertaining the distances of the closer lines; and the giving the axis of the telescope, together with the prism which is connected with it, a motion of rotation in a horizontal plane, the extent of which is read off by verniers and microscopes on an accurately graduated circle, in the same way as in astronomical observations. The apparatus employed by him for this purpose, and which is applicable to a variety of useful purposes in optical researches, is represented in fig. 96.

Fig. 96.

424. Colours of the spectrum.

The fixed lines in the spectrum do not mark any precise limits between the different colours of which it consists. According to Dr. Wollaston, (*Phil. Trans.*, 1802,) the spectrum consists of only four colours, red, green, blue, and violet; and he considers the narrow line of yellow visible in it in his mode of examination already described (looking through a prism at a narrow line of light with the naked eye) as arising from a mixture of red and green. These colours, too, he conceives to be well defined in the spaces they occupy, not graduating insensibly into each other, and of, sensibly, the same tint throughout their whole extent. We confess we have never been able quite satisfactorily to verify this last observation, and in the experiments of Fraunhofer, (which we had the good fortune to witness, as exhibited by himself at Munich,) where, from the perfect distinctness of the finest lines in the spectrum, all idea of confusion of vision, or intermixture of rays is precluded, the tints are seen to pass into each other by a perfectly insensible gradation; and the same thing may be noticed in the coloured representations of the spectrum published in the first essay of that eminent artist, and executed by himself with extraordinary pains and fidelity. The existence of a pale straw yellow, not of mere linear breadth, but occupying a very sensible space in the spectrum, is there very conspicuous, and may also be satisfactorily shown by other experiments to be hereafter described, when we come to speak of the absorption of light. In short, (with the exception of the fixed lines, which Newton's instrumental means did not enable him to see,) the spectrum is, what that illustrious philosopher originally described it, a graduated succession of tints, in which all

$$\tfrac{1}{2}\,\delta\,(\mathrm{D}-\mathrm{D}') = \frac{\delta\,\mu\,.\,\sin\dfrac{\mathrm{A}}{2}}{\cos\left(\dfrac{\mathrm{A}+\mathrm{D}}{2}\right)} - \frac{\delta\,\mu'\,.\,\sin\dfrac{\mathrm{A}'}{2}}{\cos\left(\dfrac{\mathrm{A}'+\mathrm{B}'}{2}\right)}.$$

Putting this equal to zero, we have

$$\frac{\delta\,\mu}{\delta\,\mu'}\cdot\frac{\sin\frac{1}{2}\,\mathrm{A}}{\sin\frac{1}{2}\,\mathrm{A}'} = \frac{\cos\frac{1}{2}\,(\mathrm{A}+\mathrm{D})}{\cos\frac{1}{2}\,(\mathrm{A}'+\mathrm{D}')};$$

and, eliminating $\sin\frac{1}{2}$ A and $\sin\frac{1}{2}$ A′ from this, by means of the two original equations from which we set out, we get

$$\frac{\delta\,\mu}{\delta\,\mu'}\times\frac{\mu'}{\mu} = \frac{\cos\frac{1}{2}\,(\mathrm{A}+\mathrm{D})}{\cos\frac{1}{2}\,(\mathrm{A}'+\mathrm{D}')}\times\frac{\sin\frac{1}{2}\,(\mathrm{A}'+\mathrm{D}')}{\sin\frac{1}{2}\,(\mathrm{A}+\mathrm{D})} = \frac{\tan\frac{1}{2}\,(\mathrm{A}'+\mathrm{D}')}{\tan\frac{1}{2}\,(\mathrm{A}+\mathrm{D})}.$$

Now if we call p, p' the dispersive powers of the media, or the proportional parts of the whole refractions of the extreme red ray, to which the dispersion is equal, we shall have

$$p = \frac{\delta\,\mu}{\mu-1}\quad p' = \frac{\delta\,\mu'}{\mu'-1}\ \text{ and }\ \frac{p}{p'} = \frac{\delta\,\mu}{\delta\,\mu'}\times\frac{\mu'-1}{\mu-1},$$

so that

$$\frac{p}{p'} = \frac{\mu}{\mu'}\cdot\frac{\mu'-1}{\mu-1}\cdot\frac{\tan\frac{1}{2}\,(\mathrm{A}'+\mathrm{D}')}{\tan\frac{1}{2}\,(\mathrm{A}+\mathrm{D})} = \frac{\mu'-1}{\mu-1}\cdot\frac{\sin\frac{1}{2}\,\mathrm{A}'}{\sin\frac{1}{2}\,\mathrm{A}}\cdot\sqrt{\frac{1-\mu^2\,.\,(\sin\frac{1}{2}\,\mathrm{A})^2}{1-\mu'^2\,.\,(\sin\frac{1}{2}\,\mathrm{A}')^2}}. \qquad (a)$$

Such is the strict formula, which, when A and A′ are verv small, becomes

$$\frac{p}{p'} = \frac{(\mu'-1)\,\mathrm{A}'}{(\mu-1)\,\mathrm{A}};\quad \text{or, since } (\mu-1)\,\mathrm{A} = \mathrm{D}, \text{ and } (\mu'-1)\,\mathrm{A}' = \mathrm{D}';\qquad \frac{p}{p'} = \frac{\mathrm{D}'}{\mathrm{D}}.$$

428. Dispersive powers compared by experiment.

The formula just obtained, furnishes us with an experimental method of determining the ratio of the dispersive powers of two media. For if we can by any means succeed in forming them into two prisms of such refracting angles, that, when placed in their respective positions of minimum deviation, a well defined bright object, viewed through both, shall appear well defined and free from colour at its edges; then, by measuring their angles, and knowing also from other experiments their refractive indices, the equation (a) gives us immediately the ratio in question.

429. Coloured fringes bordering objects seen through prisms explained. Fig. 99.

When we view through a prism any well defined object, either much darker or much lighter than the ground against which it is seen projected, as, for instance, a window bar seen against the sky, its edges appear fringed with colours and ill defined. The reason of this may be explained as follows:

Let A B, fig. 99, be the section of a horizontal bar seen through the prism P held with its refracting edge downwards, and first let us consider what will be the appearance of the upper edge B of the object. Since we see by light, and not by darkness, the thing really seen is not the dark object, but the bright ground on which it stands, or the bright spaces B C, A D above and below. Now the bright space B C above the object being illuminated with white light, will, after refraction at the prism, form a succession of coloured images $b\,c$, $b'\,c'$, $b''\,c''$, &c., superposed on and overlapping each other. They are represented in the figure as at different distances from P, but this is only to keep them distinct. In reality, they must be supposed to lie upon and interfere with each other. The least refracted $b\,c$ of these is red, and the most refracted $b''\,c'''$ violet, and any intermediate one (as $b'\,c'$) of some intermediate colour, as yellow for instance. Beyond b'' no image exists, so that the whole space below b'' will appear dark to an eye situated behind the prism. On the other hand, above b the images of every colour in the spectrum coexist, the bright space $b\,c$ being supposed to extend indefinitely above B. Therefore the space above b in the refracted image will appear perfectly white. Between b and b'' there will be seen, first, a general diminution of light, as we proceed from b towards b'', because the number of superposed luminous images continually decreases; secondly, an excess in all this part, of the more refrangible rays in the spectrum above what is necessary to form white light, for beyond b no red image exists, beyond b' no yellow, and so on; the last which projects beyond all, at b'', being a pure unmixed violet. Thus the light will not only decrease in intensity, but by the successive subtraction of more and more of the less refrangible end of the spectrum will acquire a bluer and bluer tint, deepening to a pure violet, so that the upper edge of the dark object will appear fringed with a blue border, becoming paler and paler till it dies away into whiteness. The reverse will happen at the lower edge A. The bright space A D forms, in like manner, a succession of coloured images, $a\,d$, $a'\,d'$, $a''\,d'$, of which the least deviated $a\,d$ is red, the most $a''\,d''$ violet, and the intermediate ones of the intermediate colours. Therefore the point a, which contains only the extreme red, will appear of a sombre red; a', which contains all the rays from red to yellow (suppose), of a lively orange red; and in proportion as the other images belonging to the more refrangible end of the spectrum come in, this tendency to an excess of red will be neutralized, and the portion beyond a'', containing all the colours in their natural proportions, will be purely white. Hence, the lower edge of the dark object will appear bordered with a red fringe, whose tint fades away into whiteness, in the same way as the blue fringe which borders the upper edge. These fringes, of course, destroy the distinctness of the outlines of objects, and render vision through a prism confused. The confusion ceases, and objects resume their natural well defined outlines, if illuminated with homogeneous light, or if viewed through coloured glasses which transmit only homogeneous rays.

434. Another method proposed by Dr. Brewster.

A simpler, perhaps, on the whole, a better, method of comparing the dispersions of two prisms, is one proposed and applied extensively by Dr. Brewster, in his ingenious Treatise *On New Philosophical Instruments*, a work abounding with curious contrivances and happy adaptations. It consists in varying, not the refracting angle of the standard prism, but the direction in which its dispersion is performed. It is manifest, that if we can produce from a line of white light, by means of a standard prism any how disposed, a coloured fringe, in which the colours occupy the same angular breadth as in that produced by a prism of unknown dispersion; then, the latter, being made to refract this fringe *in a direction perpendicular to its breadth*, and *opposite to the order of its colours*, must destroy all colour and produce a compensated refraction; and therefore if the position of the standard prism which produces such a fringe be known, the dispersion of the other may be calculated. To accomplish this, let A B be a horizontal luminous line of considerable length, and let it be refracted *downwards*, but *obliquely* in the direction A a, B b, by a standard prism whose dispersion is greater than that of the prism to be measured. Then it will form an oblique spectrum $a\,b\,b'\,a'$, $a\,b$ being the red, and $a'\,b'$ the violet; and the angular breadth of this coloured fringe will be $a\,m = a\,a' \times$ sin inclination of the plane of refraction to the horizon. Now, let the prism whose dispersion is to be measured be made to refract this coloured band *vertically upwards*; then, if the plane of the first refraction be so inclined to the horizon that the angle subtended by $a\,m$ at the eye shall be just equal to the angle of dispersion of the other prism, all the colours of the rectangular portion $b\,c\,a'\,d$ will be made to coalesce in the horizontal line A′ B′, which will appear therefore free from colour, except at its extremities A′ B′, where the coloured triangles $a\,c\,a'$, $b\,d\,b'$ will produce a red termination A′ A″ and a blue one B′ B″ at the respective ends of the line to which they correspond. Hence, if, the second prism remaining fixed, with its edge downwards and parallel to the horizon, the other or standard prism be turned gradually round in the plane perpendicular to its principal section, a position must necessarily be found where the twice refracted line A′ B′ will appear free from colour both above and below. In this position let it be arrested, and the angle of inclination of its edge to the horizon read off, its complement is the angle $a\,a'\,m$, which we will call θ. Let us now suppose each prism adjusted to its position of minimum deviation, and (as it is a matter of indifference which is placed first) let the prism to be examined or the fixed prism be placed next the object.* Then, D′ and D being the total deviations produced by the fixed and revolving prisms on the extreme red ray, we must have

Fig. 103.

$$\delta D' - \delta D \,.\, \sin\theta = o; \qquad \text{or } \delta\mu' \,.\, \sin\frac{A'}{2} \,.\, \sec\frac{A'+D'}{2} = \delta\mu \,.\, \sin\frac{A}{2} \,.\, \sec\frac{A+D}{2} \,.\, \sin\theta,$$

whence we obtain

$$\frac{p'}{p} = \frac{\delta\mu'}{\delta\mu} \,.\, \frac{\mu-1}{\mu'-1} = \frac{\mu'}{\mu} \,.\, \frac{\mu-1}{\mu'-1} \,.\, \frac{\tan\frac{1}{2}(A+D)}{\tan\frac{1}{2}(A'+D')} \,.\, \sin\theta; \qquad (c)$$

where the angles $\frac{1}{2}(A+D)$ and $\frac{1}{2}(A'+D')$ are given by the equations

$$\sin\tfrac{1}{2}(A+D) = \mu \,.\, \sin \times \tfrac{1}{2}A; \qquad \sin\tfrac{1}{2}(A'+D') = \mu' \,.\, \sin\tfrac{1}{2}A';$$

from which formula, θ being known, and also the angles and refractive indices of the two prisms, the ratio of their dispersions is found.

435. Absolute dispersive powers, how obtained. 1st. By measuring the spectrum on a screen.

By these, or other similar methods, may the dispersions of any media be compared with those of any other taken as a standard. If the media be solid, they must be formed into prisms; if fluid, they must be enclosed in hollow prisms of truly parallel plates of glass, whose angles must be accurately determined, (and one of which will serve for any number of fluids.) But to ascertain directly the dispersion of that standard prism, we must pursue a different course. The first method which obviously presents itself, is to measure the actual length of the solar spectrum cast by a prism of given refracting angle; but the light of the spectrum dies away so indefinitely at both ends, and its visible extent varies so enormously with the brightness of the sun, and the more or less perfect exclusion of extraneous light, that nothing certain can be concluded from such measures. Yet, if the brighter rays of the spectrum be destroyed, and the eye defended from all offensive light by a glass which permits only the extreme red and violet rays to pass, (see Index, *Absorption*,) some degree of accuracy may be obtained by this means. A method founded on this principle has been described by the writer of these pages in the *Transactions of the Royal Society of Edinburgh*, vol. ix. as follows: Let A and B be two vertical rectangular slits in a screen placed before an open window, the one being half the length of the other, and at a known distance from each other. The eye being guarded as above described, let the slits be refracted by the prism (in its minimum position) from the longer towards the shorter. Then will a red and violet image of each a, b, and a', b' be seen. Now let the prism be removed from the slits, (or *vice versâ*,) still preserving its position of minimum deviation, till the violet image of the longer slit exactly falls upon and covers the red image of the shorter, as in the position $a'\,b$ of the figure. Then it is obvious, that the distance between the slits, divided by their distance from the prism, is the sine of the total angle of dispersion, or is equal to δ D, and this being known

Fig. 104. 2nd. Another method.

$$\delta\mu = \frac{\delta D}{2} \quad \frac{\cos\frac{1}{2}(A+D)}{\sin\frac{1}{2}A},$$

and therefore $\frac{\delta\mu}{\mu-1}$, or p, the dispersive power, is obtained.

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* Dr. Brewster has chosen a somewhat different position, (*Treatise, &c.* p. 296,) with a view to simplify the formulæ; but it does not appear to us that any advantage is gained in that respect by his arrangement.

and its other physical properties (so far as they depend on the refrangibility of the ray) determined. Thus 1.333577 being known to be the refractive index for a ray in water, that ray can be no other than the particular ray D, whose colour is pale orange-yellow, and which is totally deficient in solar light, and peculiarly abundant in the light of certain flames. Now let x be the refractive index of any ray whatever for water, or its place in the water scale. Then it is evident, that its refractive index for any other medium must of necessity be a function of x, because the value of x determines this and all the other properties of the ray. Hence we must have between μ and x some equation which may be generally represented by $\mu = F(x)$; $F(x)$ denoting a function of x.

439. Function of refrangibility.

To determine the form of this function, we must consider, that if A be the very small angle of a prism, and D the deviation produced by it at the minimum, we have $\mu \cdot \frac{A}{2} = \frac{A+D}{2}$, or $D = (\mu - 1) A$. Hence, supposing A the refracting angle constant, the deviation is proportional to $\mu - 1$. Now, since in all media, as well as in water, the deviations observe, at least, *the same order*, being always least for the red and greatest for the violet, it follows, that in all media $\mu - 1$ increases as x increases; so that, supposing x_0 to be the index of refraction in the water scale for the first visible red ray, or the commencing value of x, and μ_0 the index for the same ray in the other medium, $(\mu - 1) - (\mu_0 - 1)$, or $\mu - \mu_0$ must increase with $x - x_0$; and since they vanish together, we may represent the one in a series with indeterminate coefficients, and powers of the other, thus

$$\mu - \mu_0 = A(x - x_0) + B(x - x_0)^2 + C(x - x_0)^3 + \&c.;$$

or, which comes to the same thing, a, b, c, &c., representing other indeterminate coefficients, ($x_0 - 1$ being constant,)

$$\frac{\mu - \mu_0}{\mu_0 - 1} = a \cdot \left(\frac{x - x_0}{x_0 - 1}\right) + b \cdot \left(\frac{x - x_0}{x_0 - 1}\right)^2 + \&c. \qquad (d)$$

440. Hypothesis of constant dispersion in all media.

The simplest hypothesis we can form respecting the values of a, b, &c. is that which makes $a = 1$, and b, and all the other coefficients vanish. This gives $\frac{\mu - \mu_0}{\mu_0 - 1} = \frac{x - x_0}{x_0 - 1}$.

We have before used $\delta\mu$ to denote what is here signified by $\mu - \mu_0$, viz. the difference between the refractive indices of any ray in the spectrum, and that at its commencement; and we have denoted by $\frac{\delta\mu}{\mu - 1}$ the same quantity which is here expressed by $\frac{\mu - \mu_0}{\mu_0 - 1}$. This then is the expression, in our present notation, of the dispersive power of the medium; and the equation now under consideration therefore indicates, that, on the hypothesis made, the dispersive power of the medium must necessarily be the same with that of water; and of course (supposing this hypothesis to be founded in the nature of light) all media must have the same dispersive power. This, as we have already seen, is not the case.

Not the law of nature.

Nor that of proportional dispersions.

The next simplest hypothesis is that which admits a as an arbitrary constant determined by the nature of the medium, but still makes b, c, &c. $= o$. This reduces the equation to

$$\frac{\mu - \mu_0}{\mu_0 - 1} = a \cdot \frac{x - x_0}{x_0 - 1};$$

consequently (if μ' and x' be any other corresponding values of μ and x) we must have also

$$\frac{\mu' - \mu_0}{\mu_0 - 1} = a \cdot \frac{x' - x_0}{x_0 - 1}, \text{ and therefore } \frac{\mu' - \mu}{\mu_0 - 1} = a \cdot \frac{x' - x}{x_0 - 1}; \text{ whence we have } \frac{\mu' - \mu}{x' - x} = a \cdot \frac{\mu_0 - 1}{x_0 - 1}.$$

Hence, if this hypothesis be correct, and μ, x and μ', x' be any two pairs of corresponding refractive indices for rays however situated, the fraction $\frac{\mu' - \mu}{x' - x}$ must be invariable. The foregoing table, however, shows very distinctly that this is far from being the case. Thus, if we take the flint glass, No. 13, the comparison of the two rays B and C gives for the value of the fraction in question 2.562; and if we compare in like manner the rays C and D, D and E, E and F, F and G, G and H respectively, we obtain the values 2.871, 3.073, 3.193, [illegible], 3.460, 3.726; the great deviation of which from equality, and their regular progression, leaves no doubt of the incompatibility of the hypothesis in question, as a general law, with nature. If we institute the same comparison for the other media in the table, we shall find the greatest diversity prevail; and if, instead of water, we assume any other as a standard, the same incompatibility will be found. Thus if the flint glass, No. 13, be compared with oil of turpentine, we find for the values of the series of fractions in question, 1.868, 1.844, 1.783, 1.843, 1.861, 1.899, which first diminish to a minimum and then increase again, &c.

441. It follows from this, that the proportion which the several coloured spaces (or the intervals B C, C D, D E, &c.) bear to each other in spectra formed by different media, is not the same in all. Thus taking the green ray E for the middle colour, and calling all that part of the spectrum which lies on the red side of E the *red*,

Light.

444. It is evident from this table, that (generally speaking) the more refractive a medium is, the greater is the extent of the blue portion of its spectrum compared with the red.

445. Achromatic refraction. If two prisms of the proper refracting angles, composed of media not very remote from each other in this list, be made to oppose each other, the secondary spectrum will be small, and the refraction almost perfectly colourless. Such a combination is said to be *achromatic*, (α-χρωμα.)

446. Dispersive powers of higher orders. Tertiary spectra. The existence of the secondary spectrum, while it renders the attainment of perfect achromaticity impossible, by the use of two media only, shows, also, that in a theoretical point of view we are not entitled to neglect the coefficients b, c, &c. of the equation (d), Art. 439. The law of nature probably requires the series to be continued to infinity; and if, by way of uniting three rays, we employ prisms of three media, *tertiary spectra*, and after them still others in succession, would doubtless be found to arise. These, however, will be small in comparison of each other.

447. Computation of their coefficients. The table (Art. 437) gives us the means of computing the coefficients on which they depend for the particular media there stated. If we put $\frac{\mu - \mu_0}{\mu_0 - 1} = \mathrm{P}$, and $\frac{x - x_0}{x_0 - 1} = p$, and suppose $\mathrm{P}, \mathrm{P}', \mathrm{P}''$, p, p', p'', &c. to be the values of P and p corresponding to the several values of μ and x set down in the table, we shall have, for determining a, b, c, &c. in any one of those media, the equations

$$\mathrm{P} = ap + bp^2 + cp^3 + \&c. \quad \mathrm{P}' = ap' + bp'^2 + cp'^3 + \&c. \quad \mathrm{P}'' = ap'' + bp''^2 + cp''^3 + \&c.$$

and as many such equations must be used as there are coefficients to determine. Confining ourselves at present to two, we find $\mathrm{P} = ap + bp^2$; $\mathrm{P}' = ap' + bp'^2$, whence

$$a = \frac{\mathrm{P}p'^2 - \mathrm{P}'p^2}{pp'(p' - p)}; \qquad b = -\frac{\mathrm{P}p' - \mathrm{P}'p}{pp'(p' - p)};$$

and, since it is desirable to select rays as far removed from each other in the spectrum as possible, we shall take μ_0 and x_0 from the column μ (B); and determine P and p by the values in the column μ (E), and P', p by those under μ (H). The results will be as follows:

Refracting media.	Dispersive powers of the first order, that of water being 1.000.	Dispersive powers of the second order, that of water being 0.000.
Flint glass, No. 13 ..	$a = +$ 1.42580	$b = +$ 7.57705
Crown glass, No. 9 ..	0.88419	2.34915
Water...............	1.00000	0.00000
Solution of potash ..	0.99626	1.13262
Oil of turpentine	1.06149	4.58639
Flint glass, No. 3....	1.29013	7.63048
Flint glass, No. 30 ..	1.37026	8.44095
Crown glass, No. 13..	0.87374	2.49199
Crown glass, letter M.	0.90131	3.49000
Flint glass, No. 23 ..	1.37578	8.66904

448. General conditions of achromaticity. *Problem.* To determine the analytical relation which must hold good in order that two prisms may form an *achromatic* combination; that is, may refract a white ray without separating the extreme colours.

Resuming the equations and notation of Art. 215, since the prisms are placed in vacuo, we have to substitute μ, $\frac{1}{\mu'}$, μ' and $\frac{1}{\mu'}$ for μ, μ', μ'', μ''', in those equations respectively, and we shall have

$$\left.\begin{array}{l} \mu \,.\, \sin \rho = \sin \alpha \\ \alpha' = \mathrm{I} + \rho \\ \sin \rho' = \mu \,.\, \sin \alpha' \end{array}\right\}(1); \qquad \left.\begin{array}{l} \mu' \,.\, \sin \alpha''' = \sin \rho''' \\ \rho'' = -\mathrm{I}'' + \alpha''' \\ \sin \alpha'' = \mu' \,.\, \sin \rho'' \end{array}\right\}(2);$$

and

$$\alpha'' = \mathrm{I}' + \rho'; \qquad \mathrm{D} = \alpha + \mathrm{I} + \mathrm{I}' + \mathrm{I}'' - \rho'''.$$

Now, since by hypothesis the incident and emergent rays are both colourless, we must have $\delta \alpha = 0$, and $\delta \mathrm{D} = 0$, that is $\delta \rho''' = 0$, the sign δ being supposed to refer to the variation of the place of the ray in the spectrum. Hence the two systems of equations (1) and (2) are exactly similar, in their form; the former as relates to $\rho, \alpha, \alpha', \rho'$, and the latter as to $\alpha''', \rho''', \rho'', \alpha''$. Now, the first system gives

$$\delta \mu \,.\, \sin \rho + \mu \,\delta \rho \,.\, \cos \rho = 0; \qquad \delta \alpha' = \delta \rho; \qquad \delta \rho' \cos \rho' = \delta \mu \,.\, \sin \alpha' + \mu \,\delta \alpha' . \cos \alpha';$$

whence, by elimination and reduction, we find

$$\delta \rho' = \frac{\sin \mathrm{I}}{\cos \rho \,.\, \cos \rho'}\, \delta \mu; \qquad (e)$$

and, consequently, by reason of the analogy of the two systems of equations pointed out above,

$$\delta\, a'' = -\frac{\sin \mathrm{I}''}{\cos a''' . \cos a''}\, \delta\, \mu' \qquad (f)$$

But, since $a'' = \mathrm{I}' + \rho'$, we have $\delta\, \rho' = \delta\, a''$, so that we finally get

$$\frac{\cos \rho . \cos \rho'}{\cos a''' . \cos a''} = -\frac{\sin \mathrm{I}}{\sin \mathrm{I}''} . \frac{\delta\, \mu}{\delta\, \mu'} . \qquad (g)$$

The property expressed by this equation may be thus stated. Conceive the ray to pass both ways outwards from a point in its course between the two prisms; then, in order that the combination may be achromatic, *the products of the cosines of its incidences on the surfaces of each prism must be to each other in the ratio compounded of that of the sines of their respective refracting angles, and the differences of their refractive indices for red and violet rays;* besides which, they must refract in opposition to each other, or I and I″ their refracting angles must have opposite signs.

449. Progress of dispersion by a single prism traced. The combination of this equation with the system of equations above stated, expressing the conditions of refraction by the prism, and their relative position with regard to each other (which is included in the equation $\alpha'' = \mathrm{I}' + \rho'$) suffice, algebraically speaking, to resolve every problem which can occur, of this kind; but the final equations are for the most part too involved to allow of direct solution. Nevertheless, the results we have arrived at will furnish occasion for remarks of moment; and, first, since ρ' is the angle of refraction from the second surface of the first prism, $\delta\, \varrho'$ is the angular breadth of the spectrum produced by it; this is, therefore, proportional, *cæteris paribus*, to the product of the secants of the angles of refraction at its two surfaces. Let us trace the progress of the variation of this, as the incident ray changes its inclination to the first surface, beginning with the case when it just grazes the surface *from* the back towards the edge. In this case $a = 90°$, $\sin \rho = \frac{1}{\mu}$, consequently ρ, and therefore $\mathrm{I} + \rho$ or α', and therefore ϱ' are all finite, and at their maximum. Hence $\cos \rho . \cos \varrho'$ is finite, and at its minimum; and therefore $\delta\, \varrho'$, or the breadth of the spectrum, is also finite, but a maximum. As the incident ray becomes more inclined to the surface ρ, and therefore a' and ϱ' diminish, and the denominator of $\delta\, \rho'$ increases, so that the breadth of the spectrum diminishes, and reaches a minimum when $\cos \rho . \cos \rho'$ attains its maximum; that is, when $d\, \rho . \tan \rho + d\, \rho' . \tan \rho' = 0$. Now

Position of least dispersion determined. this equation, substituting and reducing gives, for determining the value of ρ, and therefore of a, or the incidence when the spectrum is a minimum,

$$\mu^2 . \sin(\mathrm{I} + \rho) . \cos(\mathrm{I} + 2\,\rho) + \sin \rho = 0. \qquad (h)$$

Hence we see that the position which gives a minimum of breadth to the spectrum is very different from that which gives a minimum of deviation, being given by the above equation, which is easily resolved by a table of logarithms, and which shows at once that ρ must be greater than $45° - \frac{\mathrm{I}}{2}$.

After attaining the position so determined, the breadth of the spectrum again increases, and continues to do so till the rays can be no longer transmitted through the prism. At this limit the emergent ray just grazes the posterior face of the prism from its thinner towards its thicker part $\varrho' = 90°$, $\cos \rho' = 0$. At this limit, therefore, the dispersion becomes infinite. All these stages are easily traced by turning a prism round its edge between the eye and a candle; or, better, between the eye and the narrow slit between two nearly closed window-shutters.

450. Distortion of spectrum at extreme incidences. Fig. 105. Hence, as the incident ray varies from the position S E (fig. 105) to S′ E, and therefore the refracted from F G to F′ G′, the breadth of the spectrum commences at a maximum, but finite value, diminishes to a minimum and then increases to infinity. The distribution of the colours in the spectrum, or the breadths of the several coloured spaces in any state of the data, will moreover differ according to the values of ρ, ρ' and $\sin \mathrm{I}$; for the equation (*e*), by assigning to $\delta\, \mu$ the values which correspond in succession to the intervals between red and orange, orange and yellow, yellow and green, &c. will give the corresponding values of $\delta\, \rho'$, or the apparent breadths of these spaces. Now the denominator $\cos \rho . \cos \rho'$ is an implicit function of μ, and therefore varies when the initial ray is taken in different parts of the spectrum. The variation is trifling when the angles ρ, ρ' are considerable; but near the limit, when the ray can barely be transmitted, it becomes very great, the spectrum is violently distorted, and the violet extremity greatly lengthened in proportion to the red. The effect is the same as if the nature of the medium changed and descended lower in the order of substances in the table Art. 443.

451. Achromatic combinations of one medium. Fig. 106. From what has just been said, we see the possibility of achromatising any prism, however large its refracting angle, by any other of the same medium, however small may be its angle; for since, by properly presenting a prism to the incident ray, its dispersion may be increased to infinity; if made to refract in opposition to another whose dispersion has any magnitude, however great, it may be made to counteract, or even overcome it. Thus in fig. 106 the dispersion of the second prism *a*, of small refracting angle, being increased by the effect of its inclined position, is rendered equal and opposite to that of the prism A, whose refracting angle is large.

452. Subordinate spectra. When the prisms differ greatly in their angles, however, the second must be very much inclined, so as to bring it near to the limit of transmission. In this case, its law of dispersion, as just shown, will be greatly disturbed, and rendered totally different from what obtains in the other prisms; so that perfect achromaticity

ight. cannot be produced; but when the extreme red and violet rays are united, the green will be too little refracted by the second prism, and a purple and green spectrum will arise, as in the case of prisms of different media. To this spectrum Dr. Brewster (who was the first to place it in evidence) has given the name of a *tertiary spectrum*; but it appears to us, that this term had better be reserved for the spectra mentioned in Art. 446, and those now in question may be called *subordinate spectra*.

If a small rectangular object be viewed through such a combination as above described, in which the prism A is placed in its position of minimum deviation, and achromatised by a second a, whose angle is less than that of A, but not so small as to introduce this cause of colour, it will appear distorted in figure; for the sides parallel to the edges of the prisms will undergo no change in their apparent length, while the breadth of the rectangle will appear magnified. For the first prism, by reason of its position, does not alter the angular dimensions of objects seen through it; but the second changes their angular breadth in the ratio of $d\rho'''$ to $d\alpha''$, that is (by differentiation) in the ratio of $\frac{\cos\alpha\,.\,\cos\alpha'}{\cos\rho\,.\,\cos\rho'}$ to unity, a ratio which increases rapidly as the inclination of the prism increases, and ρ' approaches a right angle.

453. **Amici's prismatic telescope.** M. Amici has taken advantage of these properties to construct a species of achromatic telescope, which, at first sight, appears very paradoxical, being composed merely of four prisms of the *same* kind of glass, with plane surfaces. To understand its construction, conceive a small square object $o\,p$ placed with the side o parallel to the refracting edges of a pair of prisms so adjusted, and perpendicular to their principal sections, *i. e.* to the plane of the paper. Then, after refraction through both, it will be seen by an eye at E, as a real object $o'\,p'$, having its length o unaltered, but magnified in breadth. Now, if we add a second pair of prisms, similar to the first, and similarly disposed with respect to each other, so as to form a second achromatic combination, but having the plane of their principal sections at right angles to the former, producing a refraction perpendicular to the plane of the paper, or parallel to the *length* of the distorted square, this will be in like manner seen as a real and colourless object, but again distorted, its side $o'\,p'$ remaining unaltered, but o' being magnified. Thus, by the effect of the first distortion, the breadth of the square is magnified, and, by that of the second, its length, and in the same ratio; and therefore the final result will be an image undistorted, achromatic, and magnified. The writer of these pages had the pleasure of witnessing the very good performance of one of these singular telescopes, magnifying about four times in the hands of its inventor, at Modena, in 1826. It is evident, that, by superposing several such telescopes on each other, the magnifying power may be increased in geometrical progression. It is equally clear, that, by using prisms of two different media to form the several binary combinations, the *subordinate spectra* may be made to counteract the *secondary spectra*, arising from the difference in the scales of dispersion in the two media; and thus an achromaticity, almost mathematically perfect, might be obtained. It is worthy of consideration, whether, for the purpose of viewing very bright objects, as the sun, for instance, this species of telescope might not prove of considerable service. It would have the advantage of being its own darkening glass, of not bringing the rays to a focus, and therefore of requiring no extraordinary care in the figuring of the surfaces; and, in short, of being exempt from all those inconveniencies which oppose the perfection of telescopes of the usual constructions, as applied to this particular object.

454. **Conditions of achromaticity for several prisms of small angles** *Proposition.* To find the conditions of achromaticity when several prisms of different media refract a ray of white light, supposing all their refracting angles very small, and the ray to pass nearly at right angles to the principal section of each.

The refracting angles being A, A′, A″, &c., and the refractive indices μ, μ', &c., the several partial deviations will be $D = (\mu - 1)\,A$; $D' = (\mu' - 1)\,A'$, &c.; and their sum, or the total deviation, will be $(\mu - 1)\,A + (\mu' - 1)\,A' + (\mu'' - 1)\,A'' + \&c.$ In order that the emergent ray may be colourless, this must be the same for rays of all colours; and its variation, when μ, μ', &c. are made to vary, must vanish, or

$$A\,\delta\mu + A'\,\delta\mu' + A''\,\delta\mu'' + \&c. = 0.$$

Now, by equation (d) of Art. 439, we have $\delta\mu$, (or, in the notation of that article, $\mu - \mu_0$)

$$= (\mu_0 - 1)\left\{a\,.\,\frac{\delta x}{x_0 - 1} + b\left(\frac{\delta x}{x_0 - 1}\right)^2 + \&c.\right\}$$

Therefore the above equation gives, when arranged according to powers of δx,

$$\begin{aligned} 0 = &\left\{A\,(\mu_0 - 1)\,a + A'\,(\mu'_0 - 1)\,a' + A''\,(\mu''_0 - 1)\,a'' + \&c.\right\}.\,\frac{\delta x}{x_0 - 1} \\ &+ \left\{A\,(\mu_0 - 1)\,b + A'\,(\mu'_0 - 1)\,b' + A''\,(\mu''_0 - 1)\,b'' + \&c.\right\}\left(\frac{\delta x}{x_0 - 1}\right)^2 \\ &+ \&c. \end{aligned}$$

dispersive powers of the various orders for the second prism, a'', b'', &c.

this may vanish for all the rays in the spectrum, we must

$$\left.\begin{array}{l}(\mu-1)\,.\,\mathrm{A}\,a+(\mu'-1)\,\mathrm{A}'\,a'+(\mu''-1)\,\mathrm{A}''\,a''+\&\text{c.}=0\\(\mu-1)\,.\,\mathrm{A}\,b+(\mu'-1)\,\mathrm{A}'\,b'+(\mu''-1)\,\mathrm{A}''\,b''+\&\text{c.}=0\\(\mu-1)\,.\,\mathrm{A}\,c+(\mu'-1)\,\mathrm{A}'\,c'+(\mu''-1)\,\mathrm{A}''\,c''+\&\text{c.}=0\\\quad\&\text{c.}\qquad\&\text{c.}\qquad\&\text{c.}\qquad\&\text{c.}\end{array}\right\}\quad(i)$$

and so on. Generally speaking, the number of these equations being infinite, no finite number of prisms can satisfy them all; but if we attempt only to unite as many rays in the spectrum as there are prisms, which is the greatest approach to achromaticity we can attain, we have as many equations as unknown quantities, *minus* one, and the ratios of the angles to each other become known. Thus, to unite two rays two media suffice, and we can only take into consideration the first order of dispersions, which give

$$(\mu-1)\,\mathrm{A}\,a+(\mu'-1)\,\mathrm{A}'\,a'=0\,;\quad\frac{\mathrm{A}'}{\mathrm{A}}=-\frac{\mu-1}{\mu'-1}\cdot\frac{a}{a'}.\qquad(j)$$

To unite three rays we have

$$(\mu-1)\,\mathrm{A}\,a+(\mu'-1)\,\mathrm{A}'\,a'+(\mu''-1)\,\mathrm{A}''\,a''=0$$

$$(\mu-1)\,\mathrm{A}\,b+(\mu'-1)\,\mathrm{A}'\,b'+(\mu''-1)\,\mathrm{A}''\,b''=0$$

whence by elimination

$$\frac{\mathrm{A}'}{\mathrm{A}}=-\frac{\mu-1}{\mu'-1}\cdot\frac{a\,b''-b\,a''}{a'\,b''-b'\,a''}\quad\frac{\mathrm{A}''}{\mathrm{A}}=-\frac{\mu-1}{\mu''-1}\cdot\frac{a\,b'-b\,a'}{a''b'-b''a'}\,;\qquad(k)$$

and so on for any number.

453. Case of two media. Best rays to unite.

In the case of two media, if the quantities b, c, &c. be not known, the dispersive powers of the first order, a, a', should be determined, not by comparison of the extreme red and violet rays, which are too little luminous to render their strict union a matter of importance; we should rather endeavour to unite those rays which are at once powerfully illuminating, and differing much in colour, such as the rays D and F. The exact union of these will insure the approximate union of all the rest better, on the whole, than if we aimed at uniting the extremes of the spectrum, and a far greater concentration of light will be produced. This should be carefully borne in mind in all experiments on the dispersions of glass to be used in the construction of telescopes.

454. Best rays to unite in case of three media.

If we would produce the greatest possible achromaticity by three prisms, the rays to be selected for determining the values of a, b, a', b', should be C, E, and G; or, which would, perhaps, be still better, C, F, and a ray half way between D and E; but the want of a sufficiently well marked line in that part of the spectrum throws some slight difficulty in the way of this latter combination, when solar light is used, and would oblige us to have recourse to some other method of measurement, of which a variety might be suggested.

455. Cases in which the formulæ become inapplicable to practice.

In the case of three media, if the numerators and denominators of the expressions (k) vanish, or nearly so, the solutions become illusory, or at least inapplicable in practice. This happens whenever either of the fractions $\frac{a}{a'}$, $\frac{a}{a''}$, $\frac{a'}{a''}$ becomes equal to either of the corresponding fractions $\frac{b}{b'}$, $\frac{b}{b''}$, or $\frac{b'}{b''}$. Hence, to obtain practicable combinations, it is necessary to employ media which differ as much as possible in their *scales* of dispersive powers, *i. e.* in which the coloured spaces differ as far as possible from proportionality; such, for instance, as flint glass, crown glass, and muriatic acid; or, still better, oil of cassia, crown glass, and sulphuric acid, &c.

§ II. *Of the Achromatic Telescope.*

456. Chromatic aberration explained.

In the refracting telescopes described in Art. 380, &c. the different refrangibility of the differently coloured rays presents an obstacle to the extension of their power beyond very moderate limits. The focus of a lens being shorter as the refractive index is greater, it follows, that one and the same lens refracts violet rays to a focus nearer to its surface than red. This is easily seen by exposing a lens to the sun's rays, and receiving the converging cone of rays on a paper placed successively at different distances behind it. At any distance nearer to the lens than its focus for mean rays, the circle on the paper will have a red border, but beyond it a blue one; for the cone of red rays whose base is the lens, envelopes that of violet *within* the focus, its vertex lying beyond the other, but is enveloped by it *without*, for the converse reason. Hence, if the paper be held in the focus for mean rays, or between the vertices of the red and violet cones, *these* will then form a distinct image, being collected in a point: but the extreme, and all the other intermediate rays, will be diffused over circles of a sensible magnitude, and form coloured borders, rendering the image indistinct and hazy. This deviation of the several coloured rays from one focus is called the "*chromatic aberration.*"

457. Least circle of chromatic aberration. Fig. 107

The diameter of the least circle within which all the coloured rays are concentrated by a lens supposed free from spherical aberration is easily found. Thus, in fig. 107, if v be the focus for violet, and r for red rays, $n\,m\,o$ will be the diameter of this circle. Now, by similar triangles, $n\,o=\mathrm{A\,B}\,.\,\frac{m\,v}{\mathrm{C}\,v}$, and also $n\,o=\mathrm{A\,B}\,.\,\frac{m\,r}{\mathrm{C}\,r}$;

therefore equating these $\frac{m\,v}{C\,v} = \frac{m\,r}{C\,r}$, and $m\,v = m\,r\,.\,\frac{C\,v}{C\,r}$, $m\,v + m\,r = m\,r\,.\,\frac{C\,r + C\,v}{C\,r} = r\,v$, consequently $m\,r = r\,v\,.\,\frac{C\,r}{C\,r + C\,v} = r\,v\,.\,\frac{C\,r}{2\,C\,r - r\,v} = \frac{r\,v}{2}$ very nearly, since the dispersion is small in comparison with the whole refraction. Therefore $n\,o = \frac{A\,B}{2}\,.\,\frac{r\,v}{C\,r}$. Now, f being the reciprocal focal distance $(= L + D = (\mu - 1)\,(R' - R'') + D)$ we have $r\,v = -\,\delta\,\frac{1}{f} = \frac{\delta\,f}{f^2} = \frac{\delta\,\mu\,(R' - R'')}{f^2}$ $= \frac{\delta\,\mu}{\mu - 1}\,.\,\frac{L}{f^2}$ and $C\,r = \frac{1}{f}$, supposing μ to represent the index of refraction for extreme red rays. Hence we get diameter of least circle of chromatic aberration = semi-aperture $\times\ \frac{L}{f}\,.\,\frac{\delta\,\mu}{\mu - 1}$

$$= \text{semi-aperture} \times \text{dispersive index} \times \frac{L}{f}\,;$$

and for parallel rays, when $L = f$, simply semi-aperture × dispersive index.

458. Use of very long telescopes. *Corol.* Hence the circle of least colour has the same absolute linear magnitude whatever be the focal length of the lens, provided the aperture be the same. Now, in the telescope, the magnifying power, or the absolute linear magnitude of the image viewed by a given eye-glass, increases in the ratio of the focal length of the object-glass, (382.) Therefore, by increasing the focal length of an object-glass without increasing its aperture, the breadth of the coloured border round the image of any object diminishes in proportion to the image itself, and thus the confusion of vision is diminished, and the telescope will possess a proportionally higher magnifying power. In consequence of this property, before the invention of the achromatic telescope, astronomers were in the habit of using refracting telescopes of enormous length, even so far as 100 or 150 feet; and Huyghens, in particular, distinguished himself by the magnitude and excellent workmanship of his glasses, and by the important astronomical discoveries made with them.

459. Principle of the achromatic telescope. The achromatic object-glass, however, by enabling us to reduce the length of the telescope within more reasonable bounds, has rendered it a vastly more manageable and useful instrument. To conceive its principle, we have only to recur to what has already been said in Art. 451—454, respecting achromatic prisms. A lens is nothing more than a system of infinitely small prisms arranged in circular zones round a centre, with refracting angles increasing as their distance from the centre increases, so as to refract all the rays to one point; and if we can achromatise each elementary prism, the whole system is achromatic. The equations (i) apply at once to this view of the structure of a lens. For, suppose R', R'' to be the curvatures of the two surfaces of the first lens, L' its power, and μ' its refractive index, then, for a given aperture, or at a given distance from the centre, $R' - R''$, the difference of the curvatures, expresses the angle made by tangents to the surfaces, or the refracting angle of the elementary prism; or $R' - R'' = A'$; and similarly for the other lenses, $A'' = R''' - R^{iv}$, and so on, so that the equations become

$$(\mu' - 1)\,(R' - R'')\,.\,a' + (\mu' - 1)\,(R''' - R^{iv})\,a'' + \&c. = 0\ \&c.\,;$$

General equations of achromaticity. that is simply

$$\left.\begin{aligned} L'\,.\,a' + L''\,.\,a'' + L'''\,.\,a''' + \&c. &= 0 \\ L'\,.\,b' + L''\,.\,b'' + L'''\,.\,b''' + \&c. &= 0 \\ L'\,.\,c' + L''\,.\,c'' + L'''\,.\,c''' + \&c. &= 0 \\ \&c. \qquad\qquad & \end{aligned}\right\}. \qquad (a)$$

460. Otherwise deduced. These equations afford all the relations necessary to insure achromaticity; and when satisfied, since they do not contain D, they show that an object-glass which is achromatic for any one distance of the object is so for all distances. It is evident, that the same system of equations may be obtained directly from the expression in Art. 265 for the joint power of a system of lenses whose individual powers are L', L'', &c. For the condition of achromaticity gives $\delta\,L = 0$, that is

$$\delta\,L' + \delta\,L'' + \delta\,L''' + \&c. = 0.$$

But since $L' = (\mu' - 1)\,(R' - R'')$ &c. (according to the system of notation there adopted)

$$\delta\,L' = (R' - R'')\,\delta\,\mu' = L'\,.\,\frac{\delta\,\mu'}{\mu' - 1}.$$

But in the equation (d) if we put in succession for μ_0 the values μ', μ'', &c., for $\mu - \mu_0$ respectively, $\delta\,\mu'$, $\delta\,\mu''$, &c., and for a, b, &c. the systems of coefficients a', b', &c.; a'', b'', &c.; and suppose $\frac{x - x_0}{x_0 - 1} = p$, we shall have

$$\frac{\delta\,\mu'}{\mu' - 1} = a'\,p + b'\,p^2 + \&c.\,; \qquad \frac{\delta\,\mu''}{\mu'' - 1} = a''\,p + b''\,p^2 + \&c\,;$$

and therefore

$$0 = \mathrm{L}' \{ a' p + b' p^2 + \&c. \} + \mathrm{L}'' \{ a'' p + b'' p^2 + \&c. \} + \&c.$$

which, being made to vanish independently of p, gives the very same system of equations as (*a*.)

461. Object glass of two media. To satisfy all these equations at once with any finite number of lenses being impossible, we must rest content with satisfying as many of the most important as the number of lenses will permit. Thus, if we have two lenses of different media, such as flint and crown glass, for instance, one only of them can be satisfied, and this must of course be the first, viz.

$$\mathrm{L}' a' + \mathrm{L}'' a'' = 0, \quad \text{or} \quad \frac{\mathrm{L}''}{\mathrm{L}'} = -\frac{a'}{a''}; \qquad (b)$$

which shows that the powers of the lenses must oppose each other, and be to each other inversely (and of course their focal lengths directly) as the dispersive powers. In such a combination, the values of a', a'', the dispersive powers, however, ought not to be obtained from the relative refractions for the extreme red and violet rays of the spectrum, (according to the remark in Art. 453,) but rather from the strongest and brightest rays whose colours are in decided contrast; such, for instance, as the rays C and F in Fraunhofer's scale.

462. Object glass of three media. With three lenses of different media, two of the equations of achromaticity can be satisfied, and the secondary spectrum corrected, thus we have

$$\left.\begin{aligned} 0 &= \mathrm{L}' a' + \mathrm{L}'' a'' + \mathrm{L}''' a''' \\ 0 &= \mathrm{L}' b' + \mathrm{L}'' b'' + \mathrm{L}''' b''' \end{aligned}\right\} \left\{\begin{aligned} \frac{\mathrm{L}''}{\mathrm{L}'} &= -\frac{a' b''' - b' a'''}{a'' b''' - b'' a'''} \\ \frac{\mathrm{L}'''}{\mathrm{L}'} &= -\frac{a' b'' - b' a''}{a''' b'' - b''' a''} \end{aligned}\right\}; \qquad (c)$$

and in determining the values of a', b', &c. the rays to be employed should be the brightest yellow for a middle ray, and a pretty strong red and blue for the extremes. The rays B, E, H are perhaps inferior to C, E, G for this purpose.

463. Hence in a double object-glass having a positive focus the least dispersive lens must be of a convex or positive, and the most so of a negative, or concave character. The order in which they are placed is of no consequence, as far as achromaticity is concerned.

464. Simultaneous destruction of both aberrations. A single lens, as we have seen, neither admits of the destruction of the spherical, nor chromatic aberration, (Art. 296 and 457;) but if we combine two or more lenses of different media, the equations s, t, u, v of Art. 309, 310, 312, and 313, combined with the equations just derived (*a*), Art. 459, or so many of them as are not incompatible, afford us the means of annihilating both species of aberration at once; and what is curious, and must be regarded as singularly fortunate, the relations afforded by the destruction of the chromatic aberration, which, at first sight, would appear likely greatly to complicate the inquiry, tend, on the contrary, remarkably to simplify it, being in fact the very relations the analyst would fix upon to limit his symbols, and give his final equations the greatest simplicity their nature admits, if left at his disposal. For, it will be remarked, that in the general equation for the destruction of the spherical aberration, $\Delta f = 0$, or

$$0 = \frac{\mathrm{L}'}{\mu'} (\alpha' - \beta' \mathrm{D}' + \gamma' \mathrm{D}'^2) + \frac{\mathrm{L}''}{\mu''} (\alpha''' + \beta'' \mathrm{D}'' + \gamma'' \mathrm{D}''^2) + \&c.; \qquad (d)$$

the expressions within the parentheses are all of the second degree when expressed in terms of the curvatures of the surfaces, and of $\mathrm{D}' = \mathrm{D}$ the proximity of the radiant point to the first lens; and as L', L'', &c. are respectively of the first degree, in terms of the curvatures, the whole is, in its general form, of the third degree, and the equation of a cubic form. But the conditions of achromaticity, which assign relations only between L', L'', &c. without involving R', R'', &c. enable us to eliminate these quantities and replace them in the above equation, by giving combinations of a', a'', b', b'', &c., so that it becomes reduced to a quadratic form, and its treatment simplified accordingly.

465. Determination of the powers of the several lenses. Let us proceed now to develope the equation (*d*), in which, according to the foregoing remark, when the conditions of achromaticity are introduced, L', L'', &c. may be regarded as given quantities; for, taking $\mathrm{L} = \mathrm{L}' + \mathrm{L}'' + \&c.$ = the power of the compound lens, (which we may suppose given, or, if we please, assume equal to unity,) this, combined with the equations (*a*), determines the values of L', &c. Thus, in the case of two lenses, if we put π for the ratio of the dispersive powers, or $\varpi = \frac{a'}{a''}$ we have $\mathrm{L}' = \frac{\mathrm{L}}{1 - \omega}$, $\mathrm{L}'' = -\frac{\varpi \mathrm{L}}{1 - \varpi}$; and similarly for three or more lenses. Suppose then we represent by r', r'', r''', &c. the respective curvatures of the first, or *anterior* surfaces of the first, second, third, &c. lens, in order; the first being that on which the rays first fall.

Developement of the general equation. Then we have $\mathrm{L}' = (\mu' - 1)(\mathrm{R}' - \mathrm{R}'') = (\mu' - 1)(r' - \mathrm{R}'',)$ so that $\mathrm{R}'' = r' - \frac{\mathrm{L}'}{\mu' - 1}$; and similarly $\mathrm{R}^{\mathrm{iv}} = r'' - \frac{\mathrm{L}''}{\mu'' - 1}$, &c. We must therefore put in the foregoing expressions

$$\mathrm{R}' = r'; \qquad \mathrm{R}'' = r' - \frac{\mathrm{L}'}{\mu' - 1}; \qquad \mathrm{R}''' = r''; \qquad \mathrm{R}^{\mathrm{iv}} = r'' - \frac{\mathrm{L}''}{\mu'' - 1}, \ \&c.$$

Hence by substitution of these in the values of α, β, &c. (Art. 293) we get

$$\alpha' = (2+\mu')\,r'^2 - (2\mu'+1)\,.\,\frac{\mu'}{\mu'-1}\,.\,L'r' + \mu'\,.\left(\frac{\mu'}{\mu'-1}\right)^2 L^2$$

$$\beta' = (4+4\mu')\,r' - (3\mu'+1)\,.\,\frac{\mu'}{\mu'-1}\,L'$$

$$\gamma' = 2+3\mu',$$

and similarly for α'', β'', γ'', &c. So that, substituting again these expressions, and putting for D'' its equal $L'+D'$, for D''' its equal $L'+L''+D'$, and so on, we have, finally, for the general equation $\Delta f = 0$, as follows:

$$\begin{aligned}
0 = &\left\{\left(\frac{2}{\mu'}+1\right)L'r'^2 + \left(\frac{2}{\mu''}+1\right)L''r''^2 + \left(\frac{2}{\mu'''}+1\right)L'''r'''^2 + \text{\&c.}\right\}\\
&- \left\{\frac{2\mu'+1}{\mu'-1}L'^2r' + \frac{2\mu''+1}{\mu''-1}L''^2r'' + \frac{2\mu'''+1}{\mu'''-1}L'''^2r''' + \text{\&c.}\right\}\\
&- 4\left\{\left(1+\frac{1}{\mu''}\right)L'L''r'' + \left(1+\frac{1}{\mu'''}\right)(L'+L'')\,L'''r''' + \text{\&c.}\right\}\\
&+ \left\{\left(\frac{\mu'}{\mu'-1}\right)^2L'^3 + \left(\frac{\mu''}{\mu''-1}\right)^2L''^3 + \left(\frac{\mu'''}{\mu'''-1}\right)^2L'''^3 + \text{\&c.}\right\}\\
&+ \left\{\frac{3\mu''+1}{\mu''-1}L'L''^2 + \frac{3\mu'''+1}{\mu'''-1}(L'+L'')\,L'''^2 + \text{\&c.}\right\}\\
&+ \left\{\left(\frac{2}{\mu''}+3\right)L'^2L''^2 + \left(\frac{2}{\mu'''}+3\right)(L'+L'')^2L''' + \text{\&c.}\right\}\\
&+ D\,.\left\{\begin{array}{l}
-4\left\{\left(1+\frac{1}{\mu'}\right)L'r + \left(1+\frac{1}{\mu''}\right)L''r'' + \left(1+\frac{1}{\mu'''}\right)L'''r''' + \text{\&c.}\right\}\\
+\left\{\frac{3\mu'+1}{\mu'-1}L'^2 + \frac{3\mu''+1}{\mu''-1}L''^2 + \frac{3\mu'''+1}{\mu'''-1}L'''^2 + \text{\&c.}\right\}\\
+2\left\{\left(\frac{2}{\mu''}+3\right)L'L'' + \left(\frac{2}{\mu'''}+3\right)(L'+L'')\,L''' + \text{\&c.}\right\}
\end{array}\right\}\\
&+ D^2\left\{\left(\frac{2}{\mu'}+3\right)L' + \left(\frac{2}{\mu''}+3\right)L'' + \left(\frac{2}{\mu'''}+3\right)L''' + \text{\&c.}\right\}.
\end{aligned}$$

466. For brevity, let us represent by X, the terms of this expression, independent of the quantity D; by Y, the assemblage of terms multiplied by D'; and by Z, those multiplied by D'^2, and we shall have

$$\Delta f = \frac{y^2}{2}\,\{X + Y\,.\,D + Z\,.\,D^2\};$$

and if this vanish the aberration is destroyed. Now, first, if we regard only parallel rays, or suppose $D=0$, this reduces itself to $X=0$, so that the condition $X=0$ being satisfied, the telescope will be perfect when used for astronomical purposes, or for viewing objects so distant that D' may be disregarded.

The distinction of aberration an indeterminate problem.

Conditions limiting it. Clairaut's.

467. The equation $X=0$ is of the second degree in each of the quantities r' r'', &c., whose number is that of the lenses. Consequently, this condition alone is not sufficient to fix their values; and, without assuming some further relations between them, or some other limitations, the problem is indeterminate, and the aberration may be destroyed in an infinite variety of ways. Confining ourselves at present to the consideration of two lenses only, since $X=0$ contains only two unknown quantities, one other equation only is required, and we have only to consider what other condition will be attended with the greatest practical advantages. Clairaut has proposed to adjust the two lenses so as to have their adjacent surfaces in contact throughout their whole extent, to allow of their being cemented together, and thus avoid the loss of light by reflection at these surfaces. This certainly would be a great advantage were it possible so to cement two glasses of large size together, as to bring neither of them into a state of strain as the cement cools, or otherwise fixes; and were it not for the further inconvenience, that the media being of course differently expansible by heat, every subsequent change of temperature would necessarily distort their figure, as well as strain their parts, when thus forcibly held together, just as we see a compound lamina of two differently expansible metals assume a greater or less curvature, according to the temperature it is exposed to. Meanwhile the condition in question is algebraically expressed by $L' = (\mu'-1)(r'-r'')$; for in this case $R' = r'$, and $R'' = R''' = r''$, and this being of the first degree only in r', r'', affords a final equation of a quadratic form by elimination with $X=0$, which latter, in the case before us of two lenses, is the same as the equation (v), Art. 312, writing only r' for R', and r'' for R'''.

But this condition of Clairaut's has another and much greater inconvenience, which is, that the resulting quadratic has its roots imaginary, when the refractive and dispersive powers of the glasses are such as are by no means unlikely to occur in practice; and without the limits of refraction and dispersion, for which they are real, the resulting curvatures change so rapidly on slight variations of the data, as to make their computation delicate, and interpolation between them, so as to form a table, very troublesome. D'Alembert, in his *Opuscules*, tom. iii., has proposed a variety of other limitations, such, for instance, as annihilating the spherical aberration for rays of all colours, (which comes to the same as supposing at once $X = 0$ and $\frac{\delta X}{\delta \mu'} \delta \mu' + \frac{\delta X}{\delta \mu''} \delta \mu'' = 0$, and which leads to biquadratic equations, and affords no practical advantage,) &c. But, without going into useless refinements of this kind, the very form of the general equation $X + Y . D' + Z . D'^2 = 0$ points out a condition combining every advantage the case is susceptible of. This consists in putting $Y = 0$. By this supposition, the term depending on D' is destroyed, without assuming $D' = 0$; so that the telescope is not only perfect for parallel rays, but admits of as considerable a proximity of the object without losing its aplanatic character, as the nature of the case will allow. The term $Z . D'^2$ indeed, or

468. D'Alembert's.

Another proposed.

$$D'^2 . \left\{ \left(\frac{2}{\mu'} + 3\right) L' + \left(\frac{2}{\mu''} + 3\right) L'' + \&c. \right\},$$

cannot vanish when two lenses only are used, being composed wholly of given functions of the refractive and dispersive powers, unless by D' itself vanishing, or by an accidental adjustment of the values of μ', μ'', L', &c. But except the object be brought within a comparatively small distance from the telescope, (such as ten times its own length,) the square of D' is always so small as to allow of our disregarding this term, and considering the instrument as perfectly aplanatic when $Y = 0$. Now this equation, being of the first degree in r', r'', adds no new algebraic difficulty to the problem, but leads by elimination to a final quadratic; and, what is of most consequence, for such values of μ', μ'', and the dispersive ratio ϖ as occur in practice, the roots of this quadratic are always real, and the resulting curvatures of all the surfaces are moderate, and well adapted for practice; more so, indeed, than in any construction hitherto proposed. They are, moreover, such as to afford remarkable and peculiar facilities for interpolation, as we shall presently see. These reasons seem to leave no room for hesitation in fixing on the condition $Y = 0$, as that which ought to be introduced to limit the problem of the construction of a double object-glass, and to render it, so far as it can be rendered, *aplanatic*.

This equation, in the case in question, is 469

$$0 = 4\left(1 + \frac{1}{\mu'}\right) L' r' + 4\left(1 + \frac{1}{\mu''}\right) L'' r''$$

$$- \frac{3\mu' + 1}{\mu' - 1} L'^2 - \left(6 + \frac{4}{\mu''}\right) L' L'' - \frac{3\mu'' + 1}{\mu'' - 1} L''^2; \qquad (f)$$

470 which is to be combined with (v), Art. 412, in which $R' = r'$ and $R''' = r''$. To reduce these to numbers, μ', μ'' and the dispersive ratio ϖ must first be known. The readiest and most certain way in practice, for the use of the optician, is to form small object-glasses from specimens of the glasses intended to be employed, and by trial work them till the combination is as free from colour as possible, by the test usually had recourse to in practice. This is, to examine with a high magnifying power the image of a well defined white circle, or circular annulus on a black ground. If its edges are totally free from colour, the adjustment is perfect, but (owing to the secondary spectrum) this will seldom be the case; and there will generally be seen on the interior edge of the annulus a faint green, and on the exterior a purplish border, when the telescope is thrown a little out of focus by bringing the eye-glass too near the object-glass, and *vice versâ*. The reason is, that while the great mass of orange and blue rays is collected in one focus, the red and violet are converged to a focus farther from, and the green to one nearer to the object-glass; the refraction of the green rays being in favour of the *convex* or *crown* glass, and of the red and violet (which united form purple) in favour of the flint (see table, Art. 443) or concave lens. The focal lengths of the lenses are then to be accurately determined, and the ratio of the dispersions (ϖ) will then be known, being the same with that of the focal lengths (454). The refractive indices will be best ascertained by direct observation, forming portions of each medium into small prisms. Now, ϖ being known, if we take unity for the power of the compound lens, we have $L' = \frac{1}{1 - \varpi}$ and $L'' = -\frac{\varpi}{1 - \varpi}$, so that L' and L'' are known, and we have therefore only to substitute their values and those of μ', μ'', in the algebraic expressions, and proceed to eliminate by the usual rules. The following compendious table contains the result of such calculations for the values of μ', μ'' and ϖ therein stated, together with the amount of variation produced by varying either of the refractive indices independently of the other, for the sake of interpolation by proportional parts. Fig. 108 is a representation of the resulting object-glass.

Dimensions of an aplanatic object-glass.

Table for finding the Dimensions of an Aplanatic Object-glass.

Refractive index of crown, or convex lens $= \mu' = 1.524$.

Refractive index of flint, or concave lens $= \mu'' = 1.585$.

Compound focal length $= 10.000$.

	CROWN LENS.					FLINT LENS.				
	First surface, convex.			Second surface, convex.		Third surface, concave.	Fourth surface, convex.			
Dispersive ratio $\varpi =$.	Radius for the above refractive indices.	Variation of radius for a change of +0.010 in ref. index of crown glass.	Variation of radius for a change of +0.010 in ref. index of flint glass.	Radius of convexity.	Focal length of crown lens.	Radius of concavity.	Radius for the above refractive indices.	Variation of radius for a change of +0.010 in ref. index of crown glass.	Variation of radius for a change of +0.010 in ref. index of flint glass.	Focal length of flint lens.
0.50	6.7485	+ 0.0500	− 0.0030	4.2827	5.0	4.1575	14.3697	+ 0.9921	− 0.3962	10.0000
0.55	6.7184	+ 0.0740	− 0.0011	3.6332	4.5	3.6006	14.5353	+ 1.0080	− 0.5033	8.1818
0.60	6.7069	+ 0.0676	+ 0.0037	3.0488	4.0	3.0640	14.2937	+ 1.1049	− 0.5659	6.6667
0.65	6.7316	+ 0.0563	+ 0.0125	2.5208	3.5	2.5566	13.5709	+ 1.1614	− 0.6323	5.3846
0.70	6.8279	+ 0.0335	+ 0.0312	2.0422	3.0	2.0831	12.3154	+ 1.1613	− 0.7570	4.2858
0.75	7.0816	− 0.0174	+ 0.0568	1.6073	2.5	1.6450	10.5186	+ 1.0847	− 0.7207	3.3333

471. Example of the use of the table.

To apply this table to any other proposed state of the data, we have only to consider that to compute the radius of any one of the surfaces, as the first or fourth, we have only to regard each element as varying separately, and take proportional parts for each. The following example will elucidate the process: Required the dimensions for an object-glass of 30 inches focus, the refractive index of the crown glass being 1.519, and that of the flint 1.589; the dispersive powers being as 0.567 : 1, or 0.567 being the dispersive ratio. Here $\mu' = 1.519$, $\mu'' = 1.589$, and $\varpi = 0.567$. The computation must first be instituted for a compound focus $= 10.000$, as in the table, and we proceed thus:

1st. Subtract the decimal (0.567) representing the dispersive ratio from 1.000, and 10 times the remainder $(= 10 \times 0.433 = 4.330)$ is the focal length of the crown lens.

2nd. Divide unity by the decimal above mentioned, (0.567,) subtract 1.000 from the quotient $\left(\frac{1}{0.567} = 1.7635, \text{ minus } 1 = 0.7635\right)$ and the remainder multiplied by 10 (or 7.635) is the focal length of the flint lens. We must next determine by the tables the radii of the first and fourth surfaces for the dispersive ratios there set down (0.55 and 0.60) next less and next greater than the given one. For this purpose we have

Refractive powers given..........	1.519 and	1.589
Refractive powers in table	1.524 ..	1.585
Differences	− 0.005	+ 0.004

The given refraction of the crown being less, and of the flint greater, than their average values on which the table is founded. Looking out now opposite to 0.55 in the first column for the variations in the two radii corresponding to a change of + 0.010 in the two refractions, we find as follows:

	First surface.	Fourth surface.
For a change = + 0.010 in the crown	+ 0.0740	+ 1.0080
For a change = + 0.010 in the flint	− 0.0011	− 0.5033

But the actual variation in the crown instead of + 0.010 being − 0.005, and of the flint + 0.004, we must take the proportional parts of these, changing the sign in the former case; thus we find the variations in the first and last radii to be

	First surface.	Fourth surface.
For − 0.005 variation in the crown	− 0.0370	− 0.5040
For + 0.004 variation in the flint ..	− 0.0004	− 0.2013
Total variation from both causes	− 0.0374	− 0.7053
But the radii in the table are	6.7184	14.5353
Hence the radii interpolated are	6.6810	13.8300

If we interpolate, by a process exactly similar, the same two radii for a dispersive ratio 0.60, we shall find, respectively,

	First surface.	Fourth surface.
For a variation of − 0.005 in the crown	− 0.0338	− 0.5524
For a variation of + 0.004 in the flint	+ 0.0015	− 0.2264
Total variation	− 0.0323	− 0.7788
Radii in table	6.7069	14.2937
Interpolated radii	6.6746	13.5149

Having thus got the radii corresponding to the actual refractions for the two dispersive ratios 0.55 and 0.60, it only remains to determine their values for the intermediate ratios 0.567 by proportional parts; thus

		First radius.	Fourth radius.
For	0.600	6.6746	13.5149
For	0.550	6.6810	13.8300
Differences	+ 0.050	− 0.0064	− 0.3151

$$0.050 : 0.567 - 0.050 = 0.017 :: -0.0064 : -0.0022$$
$$0.050 : 0.017 :: -0.3151 : -0.1071$$

So that 6.6810 − 0.0022 = 6.6788, and 13.8300 − 0.1071 = 13.7229, are the true radii corresponding to the given data. Thus we have, for the crown lens, focal length $= 4.330 = \frac{1}{L'}$, radius of first surface $= 6.6788 = \frac{1}{R'}$, index of refraction $= 1.519 = \mu'$, whence by the formula $L' = (\mu' - 1)(R' - R'')\frac{1}{R''}$ radius of the other surface is − 3.3868. Again, for the flint lens, the focal length $= \frac{1}{L''} = -\ 7.635$, radius of the posterior surface $= \frac{1}{R^{iv}} = -\ 13.7729$, index of refraction $\mu'' = 1.589$, whence we find $\frac{1}{R'''} = -\ 3.3871$ for the radius of the other surface. The four radii are thus obtained for a focal length of 10 inches, and multiplying by 3 we have for the telescope proposed

radius of first surface = + 20.0364 in.; of second, − 10.1604 in.; of third, − 10.1613 in.; of fourth, − 41.1687 in.

Here, then, we see that the radii of the two interior surfaces of the double lens (fig. 108) differ by scarcely more than a thousandth part of an inch; so that, should it be thought desirable, they may be cemented together. This is not merely a casual coincidence, for the particular state of the data; if we cast our eyes down the table we shall find this approximate equality of the interior curvatures (those of the second and third surfaces) maintained in a singular manner throughout the whole extent of the variation of ϖ. Thus the construction, here proposed in reality for glasses of the ordinary materials, approaches considerably to that of Clairaut already mentioned. 472.

In order to put these results to the test of experience, Mr. South procured an achromatic telescope to be executed on this construction by Mr. Tulley, one of the most eminent of our British artists, which is now in the possession of J. Moore, Esq. of Lincoln. Its focal length was 45 inches, and aperture 3½, and its performance was found to be fully adequate to the expectation entertained of it, bearing a magnifying power of 300 with perfect distinctness, and separating easily a variety of double stars, &c. A more minute account of its performance will be found in the *Journal of the Royal Institution*, No. 26. Should the splendid example set by Fraunhofer be followed up, and the practice of the optician be in future directed by a rigorous adherence to theory, grounded on exact measurements of the refractive powers of his glasses on the several coloured rays, it will become necessary to develope the above table more in detail. 473.

474. Object-glasses of three media

When three media are employed in the construction of object-glasses, it should be our object to obtain as great a difference as possible in their scales of action on the differently coloured rays. Dr. Blair, to whom we are indebted for the first extensive examination of the dispersive powers of media as a physical character, and who first perceived the necessity of destroying the secondary spectrum, and pointed out the means of doing it, is the only one hitherto who has bestowed much pains on this important part of practical optics; which, considering the extraordinary success he obtained, and the perfection of the telescopes constructed on his principles, is to be regretted. We have no idea, indeed, for the reasons already mentioned, that very large object-glasses, enclosing fluids, can ever be rendered available; but to render glasses of moderate dimensions more perfect, and capable of bearing a higher degree of magnifying power, is hardly less important as an object of practical utility. His experiments are to be found in the *Transactions of the Royal Society of Edinburgh*, 1791. We can here do little more than present a brief abstract of them.

475. Dr. Blair's construction of an object-glass of three media.

Dr. Blair having first discovered that the secondary fringes are of unequal breadths, when binary achromatic combinations, having equal total refractions, are formed of different dispersive media, was immediately led to consider, that by employing two such different combinations to act in opposition to each other, if the total refractions were *equal*, the ray would emerge of course undeviated, and with its primary spectrum destroyed; but a secondary spectrum would remain, equal to the difference of the secondary spectra in the two combinations. Therefore, by a reasoning precisely similar to that which led to the correction of the primary spectrum itself, (Art. 426 and 427,) if we increase the total refraction of that combination A which, *cæteris paribus*, gives the *least* secondary spectrum, its secondary colour will be increased accordingly, till it becomes equal to that of the other B; so that the emergent beam will be free from the secondary spectra altogether, and will be deviated on the whole in favour of the combination A. Reasoning on these grounds, Dr. Blair formed a compound, or binary achromatic convex lens A, (fig. 109,) of two fluids *a* and *b*, (two essential oils, such as naphtha and oil of turpentine, differing considerably in dispersion,) which, when examined alone, was found to have a greater refractive power on the green rays than on the united red and violet. He also formed a second binary lens B, of a *concave* character, and also achromatic, (*i. e.* having the primary spectrum destroyed,) consisting of the more dispersive oil (*b*) and glass, and in which the green rays are also more refracted than the united red and violet, but *in a greater degree* in proportion to the whole deviation, than in the other combination; and in precisely the same degree was the focal length of this lens increased or its refraction diminished, when compared with that of the combination A. When, therefore, these two lenses were placed together, as in fig. 109, an excess of refraction remained in favour of the convex combination; but the secondary spectra of each being equal and opposite (by reason of the opposite character of the lenses) were totally destroyed. In fact, he states, that in a compound lens so constructed, he could discover no colour by the most rigid test; and thence concluded, not only the red, violet, and green to be united, but also all the rest of the rays, no outstanding colour of blue or yellow being discernible. In placing the lenses together, the intermediate plane glasses may be suppressed altogether, as in fig. 110.

476. Remarkable property of the muriatic acid.

It was in the course of these researches that Dr. Blair was led to the knowledge of the possibility of forming binary combinations, having secondary spectra of opposite characters; that is, in which (the total refraction lying the same way) the order of the colours in the secondary spectra should be inverted. In other words, that while in some combinations the green rays are more refracted than the united red and violet, in others they are less so. He found, for instance, that while in most of the highly dispersive media, including metallic solutions, the green lay among the less refrangible rays of the spectrum, there yet exist media considerably dispersive, in which the reverse holds good. The muriatic acid, among others, is in this predicament. Hence, in binary combinations of glass with this acid, the secondary spectrum consists of colours oppositely disposed from that formed by glass and the oils, or by crown and flint glass. In consequence of this, to form an object-glass of two binary combinations, as described in the last article, they must both be of convex characters. But this affords no particular advantage. Dr. Blair, however, considered the matter in another and much more important light, as offering the means of dispensing with a third medium altogether, and producing by a single binary combination a refraction absolutely free from secondary colour. To this end he considered, that it appears to depend entirely on the chemical nature of the refracting medium, what shall be the order and distribution of the colours in the spectrum, as well as what shall be the total refraction and dispersive powers of the medium; and that therefore by varying properly the ingredients of a medium, it may be practicable, without greatly varying the total refraction and dispersion, still to produce a considerable change in the internal arrangement (if we may use the phrase) of the spectrum; and therefore, perhaps, to form a compound medium in which the seven colours shall occupy spaces regulated by any proposed law, (within certain limits.) Now if a medium could be so compounded as to have the same scale of dispersions, or the same law of distribution of the colours as crown glass with a different absolute dispersion, as we have already seen, nothing more would be required for the perfection of the *double* object-glass. The property of the muriatic acid just mentioned puts this in our power.

Dr. Blair's discovery of media having the same scale of dispersion as glass.

It is observed, that the presence of a metal (antimony, for instance) in a fluid, while it gives it a high refractive and dispersive power, at the same time tends to dilate the more refrangible part of the spectrum beyond its due proportion to the less. On the other hand, the presence of muriatic acid tends to produce a contrary effect, contracting the more refrangible part and dilating the less, beyond that proportion which they have in glass. Hence, Dr. Blair was led to conclude, that by mixing muriatic acid with metallic solutions, in proportions to be determined by experience, a fluid might be obtained with the wished for property; and this on trial he found to be the case. The metals he used were antimony and mercury; and to ensure the presence of a sufficient quantity of muriatic acid, he employed them in the state of muriates, in aqueous solution; or, in the case of mercury, in a solution of sal ammoniac, which is a compound of ammonia and muriatic acid, and which is capable of dissolving a considerably greater quantity of corrosive sublimate (muriate, or chloride of mercury) than water alone. By adding liquid muriatic acid to the compound known by the name of butter of antimony, (chloride of antimony,) or sal ammoniac to the mercurial solution, he succeeded completely in obtaining a spectrum in which the rays followed the same law of dispersion as in crown glass, and even in *over-correcting* the secondary spectrum, so as to place its exact destruction completely in his power. It only remained to form an object-glass on these principles. Fig. 111 is such an one, in which, though there are two refractions at the confines of the glass and fluid, yet the chromatic aberration, as Dr. Blair assures us, was totally destroyed, and the rays of different colours were bent from their rectilinear course with the same equality as in reflexion.

His double object-glasses formed of such media.

477. To such an extent has Dr. Blair carried these interesting experiments, that he assures us he has found it practicable to construct an object-glass of nine inches focal length, capable of bearing an aperture of three inches, a thing which assuredly no artist would ever dream of attempting with glass lenses; and we cannot close this account of his labours without joining in a wish expressed on a similar occasion by Dr. Brewster, whose researches on dispersive powers have so worthily filled up the outline sketched by his predecessor, that this branch of practical optics may be resumed with the attention it deserves, by artists who have the ready means of executing the experiments it would require. Could solid media of such properties be discovered, the telescope would become a new instrument.

478. Case of colourless single refraction at common surface of two media.

These experiments of Dr. Blair lead to the remarkable conclusion, that at the common surface of two media a white ray may be refracted without separation into its coloured elements. In fact, μ and μ' being the refractive indices of the media for any ray as the extreme red, $\frac{\mu'}{\mu}$ will be their relative refractive index for that ray, and $\frac{\mu' + \delta\mu'}{\mu + \delta\mu}$ will be the relative index for any other ray. If, then, the refractive and dispersive powers of the media be such that $\frac{\mu' + \delta\mu'}{\mu + \delta\mu} = \frac{\mu'}{\mu}$, or $\mu\,\delta\mu' = \mu'\,\delta\mu$, that is, if $\frac{\delta\mu}{\delta\mu'} = \frac{\mu}{\mu'}$; and if, moreover, this relation hold good throughout the spectrum, *i. e.* if the increments of the refractive indices, in proceeding from the red to the violet end of the spectrum, be proportional to the refractive indices themselves, then the relative index is the same for all rays, and no dispersion will take place. Now this gives a relation between the dispersive and refractive indices of the two media, viz. $\frac{p'}{p} = \frac{\mu'}{\mu} \cdot \frac{\mu - 1}{\mu' - 1} = \frac{1 - \frac{1}{\mu}}{1 - \frac{1}{\mu}}$; and, in addition to this condition, the scale of dispersions must be the same in both media. According as the dispersions differ one way or the other from this precise adjustment, the violet ray may be either more or less refracted than the red at the common surface of the two media.

479. Achromatic object-glass with separated lenses.

We shall terminate the theory of achromatic object-glasses with a problem of considerable practical importance, as it puts it in our power, having obtained an approximate degree of achromaticity in an object-glass, to complete the destruction of the colour without making any alteration in the focal lengths or curvatures of the lenses, by merely placing them at a greater or less distance from one another.

Problem. To express the condition of achromaticity, when the two lenses of a double object-glass are placed at a distance from each other, $(= t.)$

Resuming the notation of Art. 251 and 268, we have

$$f'' = \text{L}' + \text{D}; \qquad f^{\text{iv}} = \text{L}'' + \frac{f''}{1 - f''t}; \qquad \delta f'' = \delta\text{L}';$$

and

$$\delta f^{\text{iv}} = \delta\text{L}'' + \frac{\delta f''}{(1 - f''t)^2} = \delta\text{L}'' + \frac{\delta\text{L}'}{\{1 - t(\text{L}' + \text{D})\}^2}.$$

Now, that the combination may be achromatic, we must have $\delta f^{\text{iv}} = 0$; and, since t and D are constant, and L′ and L″ only vary by the variations of μ', μ'' the refractive indices, we have $\delta\text{L}' = (\text{R}' - \text{R}'')\,\delta\mu' = \frac{\delta\mu'}{\mu' - 1}\,\text{L}' = p'\,\text{L}'$, and similarly $\delta\text{L}'' = p''\,\text{L}''$, so that substituting we get

$$\{1 - t(\text{L}' + \text{D})\}^2 + \frac{p'}{p''} \cdot \frac{\text{L}'}{\text{L}''} = 0.$$

480. Such is the condition of achromaticity. Since it depends on D, it appears that if the lenses of an object-glass be not close together, it will cease to be achromatic for near objects, however perfectly the colour be corrected for distant ones. The eye therefore cannot be achromatic for objects at all distances, its lenses being of great thickness compared to their focal lengths; and, therefore, although in contact at their adjacent surfaces, yet having considerable intervals between others.

481. For parallel rays the equation becomes

$$p''\,\text{L}''(1 - t\,\text{L}')^2 = -p'\,\text{L}';$$

hence, the dispersions and powers of the lenses being given their interval t may be found by the expression

$$t = \frac{1}{\text{L}'}\left\{1 - \sqrt{-\frac{p'}{p''} \cdot \frac{\text{L}'}{\text{L}''}}\right\}.$$

482. The condition of achromaticity, were the lenses placed close together, would be, as we have already shown,

$-\frac{p'}{p''}\cdot\frac{L'}{L''}=1$. Hence, whenever this fraction is less than unity, that is whenever L′, the power of the concave or flint lens (which we here suppose to be the second) is *too great;* or when, as the opticians call it, the colour is over-corrected, the object-glass may be made achromatic, or their over-correction remedied, without regrinding the glasses, merely by separating the lenses; for in this case the quantity under the radical is less than unity, and therefore t is positive, a condition without which the rays could not be refracted as we have supposed them.

483. Moreover, this affords a practical and very easy means of ascertaining, with the greatest precision, the dispersive ratio of the two media. Let a convex lens of crown be purposely a little over-corrected by a concave of flint, and then let the colour be destroyed by separating the lenses. Measure their focal lengths $\left(\frac{1}{L'}\text{ and }\frac{1}{L''}\right)$ and the interval t between them in this state, and we have at once for the value of ϖ the dispersive ratio,

$$\varpi=\frac{p'}{p''}=-\frac{L''}{L'}(1-t\,L')^2.$$

§ III. *Of the Absorption or Extinction of Light by uncrystallized Media.*

484. All media absorb light.

Transparency is the quality by which media allow rays of light freely to pass through their substance, or, it may be, between their molecules; and is said to be more or less perfect, according as a more or less considerable part of the whole light which enters them finds its way through. Among media, consisting of ponderable matter, we know of none whose transparency is perfect. Whether it be that some of the rays in their passage encounter bodily the molecules of the media, and are thereby reflected; or, if this supposition be thought too coarse and unrefined for the present state of science, be stopped or turned aside by the forces which reside in the ultimate atoms of bodies, without actual encounter, or otherwise detained or neutralized by them; certain it is, that even in the most rare and transparent media, such as air, water, and glass, a beam of light intromitted, is gradually extinguished, and becomes more and more feeble as it penetrates to a greater depth within them, and ultimately becomes too faint to affect our organs. Thus, at the tops of very high mountains, a much greater multitude of stars is visible to the naked eye than on the plains at their feet; the weak light of the smallest of them being too much reduced in its passage through the lower atmospheric strata to affect the sight. Thus, too, objects cease to be visible at great depths below water, however free from visible impurities, &c. Dr. Olbers has even supposed the same to hold good with the imponderable media (if any) of the celestial spaces, and conceives this to be the cause why *so few* stars (not more than about five or ten millions) can be seen with the most powerful telescopes. It is probable that we shall be long without means of confirming or refuting this singular doctrine.

485. On the other hand, though no body in nature be perfectly, all are to a certain degree, transparent. One of the densest of metals, gold, may actually be beaten so thin as to allow light to pass through it; and that it passes through the substance of the metal, not through cracks or holes too small to be detected by the eye, is evident from the colour of the transmitted light, which is green, even when the incident light is white. The most opaque of bodies, charcoal, in a different state of aggregation, (as diamond,) is one of the most perfectly transparent; and all coloured bodies, however deep their hues, and however seemingly opaque, must necessarily be rendered visible by rays which have entered their substance; for if reflected at their surfaces, they would all appear white alike. Were the colours of bodies strictly superficial, no variation in their thickness could affect their hue; but, so far is this from being the case, that all coloured bodies, however intense their tint, become paler by diminution of thickness. Thus the powders of all coloured bodies, or the streak they leave when rubbed on substances harder than themselves, have much paler colours than the same bodies in mass.

486. And all absorb the different colours unequally.

This gradual diminution in the intensity of a transmitted ray in its progress through imperfectly transparent media, is termed its *absorption*. It is never found to affect equally rays of all colours, some being always absorbed in preference to others; and it is on this preference that the colours of all such media, as seen by transmitted light, depend. A white ray transmitted through a perfectly transparent medium, ought to contain at its emergence the same proportional quantity of all the coloured rays, because the part reflected at its anterior and posterior surfaces is colourless; but, in point of fact, such perfect want of colour in the transmitted beam is never observed. Media, then, are unequally transparent for the differently coloured rays. Each ray of the spectrum has, for every different medium in nature, its own peculiar *index of transparency*, just as the index of refraction differs for different rays and different media.

487. Experiment.

The most striking way in which this different absorptive power of one and the same medium on differently coloured rays can be exhibited, is to look through a plain and polished piece of smalt-blue glass, (a rich deep blue, very common in the arts—such as sugar-basins, finger-glasses, &c. are often made of,) at the image of any narrow line of light (as the crack in a window-shutter of a darkened room) refracted through a prism whose edge is parallel to the line, and placed in its situation of minimum deviation. If the glass be extremely thin, all the colours are seen; but if of moderate thickness (as $\frac{1}{10}$ inch) the spectrum will put on a very singular and striking appearance. It will appear composed of several detached portions separated by broad and perfectly black intervals, the rays which correspond to those points in the perfect spectrum being entirely extinguished. If a less thickness be employed, the intervals, instead of being perfectly dark, are feebly and irregularly illuminated, some parts of them being less enfeebled than others. If the thickness, on the other hand, be increased, the black spaces become broader, till at length all the colours intermediate between the extreme red and extreme violet are totally destroyed.

488. Law of transmission. The simplest hypothesis we can form of the extinction of a beam of homogeneous light in passing through a homogeneous medium, is, that for every equal thickness of the medium passed through, an equal aliquot part of the rays, which, up to that depth had escaped absorption, is extinguished. Thus, if 1000 red rays fall on and enter into a certain green glass, and if 100 be extinguished in traversing the first tenth of an inch, there will remain 900 which have penetrated so far; and of these one-tenth, or 90, will be extinguished in the next tenth of an inch, leaving 810, out of which again a tenth, or 81, will be extinguished in traversing the third tenth, leaving 729, and so on. In other words, the quantity unabsorbed, after the beam has traversed any thickness of the medium, will diminish in geometrical progression, as t increases in arithmetical. So that if 1 be taken for the whole number of intromitted rays, and y for the number that escape absorption in traversing an unit of thickness, y^t will represent the number escaping, after traversing any other thickness, $= t$. This only supposes that the rays in the act of traversing one stratum of a medium acquire no additional facility to penetrate the remainder. In this doctrine, y is necessarily a fraction smaller than unity, and depending on the nature both of the ray and the medium. Hence, if C represent the number of equally illuminating rays of the extreme red in a beam of white light, C′ that of the next degree of refrangibility, and so on; the beam of white light will be represented by $C + C' + C'' +$ &c.; and the transmitted beam, after traversing the thickness t, will be properly expressed by

$$C \,.\, y^t + C' \,.\, y'^t + C'' \,.\, y''^t + \text{\&c.}$$

Each term representing the intensity of the particular ray to which it corresponds, or its ratio to what it is in the original white beam.

489. It is evident from this, that, strictly speaking, total extinction can never take place by any finite thickness of the medium; but if the fraction y for any ray be at all small, a moderate increase in the thickness, (which enters as an exponent,) will reduce the fraction y^t to a quantity perfectly insensible. Thus, in the case taken above, where a tenth of an inch of green glass destroys one-tenth only of the red rays, a whole inch will allow to pass only $\left(\frac{9}{10}\right)^{10}$, or 304 rays out of a thousand, while ten times that thickness, or 10 inches, will suffer only $\left(\frac{9}{10}\right)^{100} = 0.0000266$, or less than three rays out of 100,000 to pass, which amounts to almost absolute opacity.

490. Law of absorption of any medium expressed by a curve. Fig. 112. If x be the index of refraction of any ray in the water spectrum, we may regard y as a function of x; and if on the line R V, (fig. 112,) representing the whole length of the water spectrum, we erect ordinates, R r, M N, V V equal to unity and to each other; and also other ordinates R r, M P, V v representing the values of y for the rays at the corresponding points; the curve r P v, the locus of P, will be, as it were, a type, or geometrical picture of the action of the medium on the spectrum, and the straight line R N V will be a similar type of a perfectly transparent medium. Now if this be supposed the case when the thickness of the medium is 1, if we take always $MP' : MP :: MP : MN$, and $MP'' : MP' :: MP' : MP$, &c. and so on, the loci of P′ P″, &c. will be curves representing the quantities of the rays transmitted by the thicknesses 2, 3, &c. of the medium, and so for intermediate thicknesses, or for a thickness less than 1, as in the curve $\varrho \pi v$.

491. Hence, whatever be the colour of a medium, if its thickness be infinitely diminished, it will transmit all the rays indifferently; for when $t = 0$, $y^t = 1$, whatever be y; and the curve $\rho \pi v$ approaches infinitely near to the line R′ N V′. Thus all coloured glasses blown into excessively thin bubbles are colourless, and so is the foam of coloured liquids.

492. Again, if there be any, the least, preference given by the medium to the transmission of certain rays beyond others, the thickness of the medium may be so far increased as to give it any assignable depth of tint; for if y be ever so little less than unity, and if between the values of y for different rays there be ever so little difference, t may be so increased as to make y^t as small as we please, and the ratio of y^t to y'^t as different from unity as we please.

493. In very deep coloured media all the values of y are small. If they were equal, the medium would merely stop light, without colouring the transmitted beam, but no such media are at present known.

494. Ultimate tint of an absorptive medium. Fig. 113. If the curve r P v, or the type of an absorbent medium have a maximum in any part of the spectrum, as in the green, for instance, (fig. 113;) then, whatever be the proportion in which the other rays enter, by a sufficient increase of thickness, that colour will be rendered predominant; and the *ultimate tint* of the medium, or the last ray it is capable of transmitting, will be a pure homogeneous light of that particular refrangibility to which the maximum ordinate corresponds. Thus green glasses, by an increase of thickness, become greener and greener, their type being as in fig. 113; while yellow ones, whose type is as in fig. 114, change their tint by reduplication, and pass through brown to red.

495. Tint changes by increase of thickness. This change of tint by increase of thickness is no uncommon phenomenon; and though at first sight paradoxical, yet is a necessary consequence of the doctrine here laid down. If we enclose a pretty strong solution of sap-green, or, still better, of muriate of chromium in a thin hollow glass wedge, and if we look through the edge where it is thinnest, at white paper, or at the white light of the clouds, it appears of a fine green; but if we slide the wedge before the eye gradually so as to look successively through a greater and greater thickness

Case of a green-red medium. Fig. 115.

of the liquid, the green tint grows livid, and passes through a sort of neutral, brownish hue, to a deep blood-red. To understand this, we must observe, that the curves expressing the types of different absorbent media admit the most capricious variety of form, and very frequently have several maxima and minima corresponding to as many different colours. The green liquids in question have two distinct maxima, as in fig. 115; the one corresponding to the extreme red, the other to the green, but the absolute lengths of the maximum ordinates are unequal, the red being the greater. But as the extreme red is a very feebly illuminating ray, while on the other hand the green is vivid, and affects the eye powerfully, the latter at first predominates over the former, and entirely prevents its becoming sensible; and it is not till the thickness is so far increased as to leave a very great preponderance of those obscure red rays, and subdue their rivals, as in the case represented by the lowest of the dotted curves in the figure, that we become sensible of their influence on the tint. Suppose, for instance,

Numerical illustration.

to illustrate this by a numerical example, the index of transparency, or value of y, in muriate of chromium, to be for extreme red rays, 0.9; for the mean red, orange, and yellow, 0.1; for green, 0.5; and for blue, indigo, and violet, 0.1 each; and suppose, moreover, in a beam of white light, consisting of 10,000 rays, *all equally illuminative*, the proportions corresponding to the different colours to be as follows:

Extreme red.	Red and orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
200	1300	3000	2800	1200	1000	500.

Then, after passing through a thickness equal to 1 of the medium, the proportions in the transmitted beam would be

Extreme red.	Red and orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
180	130	300	1400	120	100	50.

After traversing a second unit of thickness, they would be

Extreme red.	Red and orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
162	13	30	700	12	10	5.

and after a third, a fourth, a fifth, and sixth respectively,

Extreme red.	Red and orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
146	1	3	350	1	1	0
131	0	0	175	0	0	0
118	0	0	87	0	0	0
106	0	0	43	0	0	0.

Thus we see, that in the first of these transmitted beams the green greatly preponderates, after the second transmission, it is still the distinguishing colour; but after the third, the red bears a proportion to it large enough to impair materially the purity of its tint. The fourth transmission may be regarded as totally extinguishing all the other colours, and leaving a neutral tint between red and green; while, in all the tints produced by further successive transmissions, the red preponderates continually more and more, till at length the tint becomes no way distinguishable from the homogeneous red of the extremity of the spectrum.

496. Relative illuminative power of the several prismatic rays. Fig. 116.

Whether we suppose the obscurer parts of the spectrum to consist of fewer rays equally illuminative, or of the same number of rays of less intrinsic illuminating power with the brighter, obviously makes no difference in the conclusion, but the former supposition has the advantage of affording a hold to numerical estimation which the latter does not. In the instance here taken, the numbers are assumed at random. But Fraunhofer has made a series of experiments expressly to determine numerically the illuminating power of the different rays of the spectrum. According to which, he has constructed the curve fig. 116, whose ordinate represents the illuminative power of the ray in that part of the spectrum on which it is supposed erected, or the proportional number of equally illuminative rays of that refrangibility in white light. If we would take this into consideration in our geometrical construction, we must suppose the type of white light, instead of being a straight line, as in fig. 112.... 114, to be a curve similar to fig. 116, and the other derivative curves to be derived from it by the same rules as above. But as the only use of such representations is to express concisely to the eye the general scale of action of a medium on the spectrum, this is rather a disadvantageous than a useful refinement.

497. Fig. 117.

To take another instance. If we examine various thicknesses of the smalt-blue glass above noticed, it will be found to appear purely blue in small thicknesses. As the thickness increases, a purple tinge comes on, which becomes more and more ruddy, and finally passes to a deep red; a great thickness being, however, required to produce this effect. If we examine the tints by a prism, we shall find the type of this medium to be as in fig. 117, having four maximum ordinates, the greatest corresponding to a ray at the very farthest extremity of the red, and diminishing with such rapidity as to cause an almost perfect insulation of this ray; the next corresponds to a red of mean refrangibility, the next to the mean yellow, and the last to the violet, the ordinate increasing continually to the end of the spectrum. Thus, when a piece of such glass of the thickness 0.042 inch was used, the red portion of the spectrum was separated into two, the least refracted being a well defined band of perfectly homogeneous and purely red light, separated from the other red by a band of considerable breadth, and totally black. This red was nearly homogeneous; its tint, however, differing in no respect from the former, and being free from the slightest shade of orange. Its most refracted limit came very nearly up to the dark line D in the spectrum. A small, sharp, black line separated this red from the yellow, which was a pretty well defined band of great brilliancy and purity of colour, of a breadth exceeding that of the first red, and bounded on the green side by an obscure but not quite black interval. The green was dull and ill defined, but the violet was transmitted with very little loss. A double thickness (0.084 inch) obliterated the second red, greatly enfeebled the yellow, leaving it now sharply divided from the green, which was also extremely enfeebled. The extreme red, however, retained nearly its whole light, and the violet was very little weakened. When a great many thicknesses were laid together, the extreme red and extreme violet only passed.

498. Red media. Among transparent media of most ordinary occurrence, we may distinguish, first, those whose type has its ordinate decreasing regularly, with more or less rapidity from the red to the violet end of the spectrum, or which absorb the rays with an energy more or less nearly in some direct ratio of their refrangibility. In red and scarlet media the absorbent power increases very rapidly, as we proceed from the red to the violet. In yellow, orange, and brown ones, less so; but all of them act with great energy on the violet rays, and produce a total obliteration of them. In consequence of this, by an increase of thickness, all these media finally become red. Examples: red, scarlet, brown, and yellow glasses; port wine, infusion of saffron, permuriate of iron, muriate of gold, brandy, India soy, &c.

499. Simple green media. Among green media, the generality have a single maximum of transmission corresponding to some part of the green rays, and their hue in consequence becomes more purely green by increase of thickness. Of this kind are green glasses, green solutions of copper, nickel, &c. They absorb both ends of the spectrum with great energy; the red, however, more so, if the tint verges to blue; the violet, if to yellow. Besides these, however, are to be remarked media in which the type has two maxima; such may be termed dichromatic, having really two distinct colours. In most of these, the green maximum is less than the red; and the green tint, in consequence, loses purity by increase of thickness, and passes through a livid neutral hue to red, though this is not always the case. Examples: muriate of chrome, solution of sap-green, manganesiate of potash, alkaline infusion of the petals of the peonia officinalis and many other red flowers, and mixtures of red and blue or green media.

Dichromatic media.

500. Blue media. Blue media admit of great variety, and are generally dichromatic, having two or even a great many maxima and minima in their types; but their distinguishing character is a powerful absorption of the more luminous red rays and the green, and a feeble action on the more refrangible part of the spectrum. Among those whose energy of absorption appears to increase regularly and rapidly from the violet to the red end of the spectrum, we may place the blue solutions of copper. The best example is the magnificent blue liquid formed by supersaturating sulphate of copper with carbonate of ammonia. The extreme violet ray seems capable of passing through almost any thickness of this medium; and this property, joined to the unalterable nature of the solution, and the facility of its preparation, render it of great value in optical researches. A vessel, or tube, of some inches in length, closed at two ends with glass plates, and filled with this liquid, is the best resource for experiments on the violet rays. Ammonio-oxalate of nickel transmits the *blue* and *extreme red*, but stops the *violet*.

Insulation of the extreme violet.

501. Purple media. Purple media act by absorbing the middle of the spectrum, and are therefore necessarily always dichromatic, some of them having red and others violet for their *ultimate* or *terminal tint*. Example: solution of archil; purple, plum-coloured, and crimson glasses; acid and alkaline solutions of cobalt, &c. They may be termed red-purple and violet-purple, according to their terminal tint.

502. Combinations of media. In combinations of media, the ray finally transmitted is the residuum of the action of each. If x, y, z be the indices of transmissibility of a given ray C in the spectrum for the several media, and r, s, t their thicknesses, the transmitted portion of this ray will be $C . x^r y^s z^t$; and the residuum of a beam of white light (supposing none lost by reflexion at the surfaces) after undergoing the absorptive action of all the media, will be

$$C . x^r y^s z^t + C' . x'^r y'^s z'^t + \&c.$$

An expression which shows that it is indifferent in what order the media are placed. They may therefore be mixed, unless a chemical action take place. Thus also, by the same construction as that by which the type 1 of the first medium is derived from the straight line representing white light, may another type 2 be derived from 1, and so on; and thus an endless variety of types will originate, having so many tints corresponding to them.

503. Insulation of an extreme homogeneous red ray. This circumstance enables us to insulate, in a state of considerable homogeneity, various rays. Thus, by combining with the smalt-blue glass, already mentioned, any brown or red glass of tolerable fulness and purity of colour, a combination will be formed absolutely impermeable to any but the extreme red ray, and the refrangibility of this is so strictly definite as to allow of its being used as a standard ray in all optical inquiries, which is the more valuable, as the coloured glasses by which it is insulated are the most common of any which occur in the shops, and may be had at any glazier's. If to such a combination a green glass be added, a total stoppage of all light takes place. The same kind of glass, too, enables us to insulate the yellow ray, corresponding to the maximum Y in the type fig. 117, by combining it with a brown glass to stop out the more, and a green to destroy the less, refrangible rays, and by their means the existence of a considerable breadth of yellow light, evidently not depending on a *mixture*, or mutual encroachment of red and green, may be exhibited in the solar spectrum.

Insulation of the yellow rays.

504. Alteration of absorptive power by heat. It has been found by Dr. Brewster, that the proportions of the different coloured rays absorbed by media depend on their temperature. The tints of bodies generally deepen by the application of heat, as is known to all who are familiar with the use of the blow-pipe; thus minium and red oxide of mercury deepen in their hues by heat till they become almost black, but recover their red colours on cooling. Dr. Brewster has, however, produced instances, not merely among artificial glasses, but among transparent minerals, where a transition takes place from red to green on the application of a high temperature; the original tint being, however, restored on cooling, and no chemical alteration having been produced in the medium.

505 The analysis of the spectrum by coloured media presents several circumstances worthy of remark. First, the irregular and singular distribution in the dark bands which cross the spectrum, when viewed through such

media as have several maxima of transmission, obviously leads us to refer Fraunhofer's *Fixed lines*, and the analogous phenomena to be noticed in the light from other sources, to the same cause, whatever it may be, which determines the absorption of some ray in preference to others. It is no impossible supposition, that the deficient rays in the light of the sun and stars may be absorbed in passing through their own atmospheres, or, to approach still nearer to the origin of the light, we may conceive a ray stifled in the very act of emanation from a luminous molecule by an intense absorbent power residing in the molecule itself; or, in a word, the same indisposition in the molecules of an absorbent body to permit the propagation of any particular coloured ray through, or near them, may constitute an obstacle *in limine* to the production of the ray from them. At all events, the phenomena are obviously related, though we may not yet be able to trace the particular nature of their connection.

506. The next circumstance to be observed is, that when examined through absorbent media all idea of regular gradation of colour from one end to the other of the spectrum is destroyed. Rays of widely different refrangibility, as the two reds noticed in Art. 497, have absolutely the same colour, and cannot be distinguished. On the other hand, the transition from pure red to pure yellow, in the case there described, is quite sudden, and the contrast of colours most striking, while the dark interval which separates them, by properly adjusting the thickness of the glass, may be rendered very small without any tinge of orange becoming perceptible. What, then, we may ask, is become of the orange; and how is it, that its place is partly supplied with red on one side, and yellow on the other? These phenomena certainly lead us very strongly to believe that the analysis of white light by the prism is not the only analysis of which it admits, and that the connection between the refrangibility and colour of a ray is not so absolute as Newton supposed. Colour is a sensation excited by the rays of light, and since two rays of different refrangibilities are found to excite absolutely the same sensation of colour, there is no *primâ facie* absurdity in supposing the converse,—that two rays capable of exciting sensations of different colours may have identical indices of refraction. It is evident, that if this be the case, no mere change of direction by refractions through prisms, &c. could ever separate them; but should they be differently absorbable by a medium through which they pass, an analysis of the compound ray would take place by the destruction of one of its parts. This idea has been advocated by Dr. Brewster, in a Paper published in the *Edinburgh Philosophical Transactions*, vol. ix., and the same consequence appears to follow from other experiments, published in the same volume of that collection. According to this doctrine, the spectrum would consist of at least three distinct spectra of different colours, red, yellow, and blue, over-lapping each other, and each having a maximum of intensity at those points where the compound spectrum has the strongest and brightest tint of that colour.

507. Cases of persons who see only two colours.

It must be confessed, however, that this doctrine is not without its objections; one of the most formidable of which may be drawn from the curious affection of vision occasionally (and not very rarely) met with in certain individuals, who distinguish only two colours, which (when carefully questioned and examined by presenting to them, not the ordinary compound colours of painters, but optical tints of known composition) are generally found to be yellow and blue. We have examined with some attention a very eminent *optician*, whose eyes (or rather eye, having lost the sight of one by an accident) have this curious peculiarity, and have satisfied ourselves, contrary to the received opinion, that all the prismatic rays have the power of exciting and affecting them with the sensation of *light*, and producing distinct vision, so that the defect arises from no insensibility of the retina to rays of any particular *refrangibility*, nor to any colouring matter in the humours of the eye, preventing certain rays from reaching the retina, (as has been ingeniously supposed,) but from a defect in the sensorium, by which it is rendered incapable of appreciating exactly those differences between rays on which their colour depends. The following is the result of a series of trials, in which a succession of optical tints produced by polarized light, passing through an inclined plate of mica, in a manner hereafter to be described, was submitted to his judgment. In each case, two uniformly coloured circular spaces placed side by side, and having *complementary tints* (i. e. such that the sum of their light shall be white) were presented, and the result of his judgment is here given in his own words.

Colours according to the judgment of an ordinary eye.		Colours as named by the individual in question.		Inclination of the plate of mica to eye.
Circle to the left.	Circle to the right.	Circle to the left.	Circle to the right.	
Pale green.	Pale pink.	Both alike, no more colour sky out of window.	in them than in the cloudy	89°.5
Dirty white.	Ditto, both alike.	Both darker than before, but	no colour.	85.0
Fine bright pink.	Fine green, a little verging on bluish.	Very pale tinge of blue.	Very pale tinge of blue.	81.1
White.	White.	Yellow.	Blue.	76.3
The limit of	pink and red.	Both more coloured	than before.	
Rich grass green.	Rich crimson.	Yellow.	Blue.	74.9
		Better, but neither	full colours.	
Dull greenish blue.	Pale brick red.	Blue.	Yellow.	72.8
		Neither so rich	colours as the last.	
Purple (rather pale.)	Pale yellow.	Blue.	Yellow.	71.7
		Coming up to good colours, than a gilt picture-frame.	the yellow a better colour	
Fine pink.	Fine green.	Yellow, but has got a good deal of blue in it.	Blue, but has a good deal of yellow in it.	69.7
Fine yellow.	Purple.	Good yellow.	Good blue.	68.2
		Better colours than	any yet seen.	
Yellowish green.	Fine crimson.	Yellow, but has a good deal of blue.	Blue, but has a good deal of yellow.	67.0
Good blue, verging to indigo.	Yellow, verging to orange.	Blue.	Yellow.	65.5
		Both gay colours, particularly	the yellow to the right.	
Red, or very ruddy pink.	Very pale greenish blue, almost white.	Yellow.	Blue.	63.8
Rich yellow.	Full blue.	Fine bright yellow.	Pretty good blue.	62.7
White.	Fiery orange.	Has very little colour.	Yellow, but a different yellow, it is a blood-looking yellow.	61.2
Dark purple.	White.	A dim blue, wants light.	White, with a dash of yellow and blue.	59.5
Dull orange red.	White.	Yellow	White, with blue and yellow in it.	59.0
White.	Dull dirty olive.	White.	Dark.	57.1
Very dark purple.	White.	Dark.	White.	55.0

Instead of presenting the colours for his judgment, he was now desired to arrange the apparatus so as to make the strongest possible succession of contrasts of colour in the two circles. The results were as follow: 508.

Colours according to the judgment of an ordinary eye.		Colours as named by the individual in question.		Inclination of the plate of mica to eye.
Circle to the left.	Circle to the right.	Circle to the left.	Circle to the right.	
Pale ruddy pink.	Blue green.	Yellow.	Blue.	59.1°
Blue green.	Pale ruddy pink.	Blue.	Yellow.	65.3
Yellow.	Blue.	Yellow.	Blue.	63.1
White.	Fiery orange.	Blue.	Yellow.	61.1
Pale brick-red.	White.	Yellow.	Blue.	58.5
Indigo.	Pale yellow.	Blue.	Yellow.	54.2
Yellow.	Indigo.	Yellow.	Blue.	52.1

It appears by this, that the eyes of the individual in question are only capable of fully appreciating blue and yellow tints, and that these names uniformly correspond, in his nomenclature, to the more and less refrangible rays, generally; all which belong to the former, indifferently, exciting a sense of "blueness," and to the latter of "yellowness." Mention has been made of individuals seeing well in other respects, but devoid altogether of the sense of colour, distinguishing different tints only as brighter or darker one than another; but the case is, probably, one of extremely rare occurrence.

509. Mayer's hypothesis of three primary colours.

Mayer, in an Essay *De Affinitate Colorum*, (Opera inedita, 1775,) regards all colours as arising from three primary ones, red, yellow, and blue; regarding white as a neutral mixture of rays of all colours, and black as a mere negation of light. According to this idea, were we acquainted with any mode of mixing colours in simple numerical ratios, a scale might be formed to which any proposed colour might be at once referred. He proposes to establish such a scale in which the degrees of intensity of each simple colour shall be represented by the natural numbers 1, 2, 3. . . . 12; 1 denoting the lowest degree of it capable of sensibly affecting a tint, and 12 the full intensity of which the colour is capable, or the total amount of it existing in white light. Thus r^{12} denotes a full red of the brightest and purest tint, y^{12} the brightest yellow, and b^{12} the brightest blue. To represent mixed tints, he combines the symbols of the separate ingredients. Thus $r^{12}\,y^4$, or, more conveniently, $12\,r + 4\,y$, represents a red verging strongly to orange, such as that of a coal fire.

510. Modification of Mayer's scale.

The scale proposed is convenient and complete, so far as regards what he calls perfect colours, which arise from white light by the *subtraction* of one or more proportions of its elementary rays; but a very slight modification of his system will render it equally applicable to all, and it may be presented as follows. Suppose we fix on 100 as a standard intensity of each primary colour; or the number of rays of that colour (all supposed equally effective) which falling on a sheet of white paper, or other surface perfectly neutral, (*i. e.* equally disposed to reflect all rays) shall produce a full tint of that particular kind, and let us denote by such an expression as $x\,\mathrm{R} + y\,\mathrm{Y} + z\,\mathrm{B}$, the tint produced by the incidence of x such rays of primary red, y such rays of yellow, and z such rays of blue on the same surface together. It is obvious then, that the different numerical values assigned to x, y, z, from 1 to 100, will give different symbols of tints, whose number will be $100 \times 100 \times 100 = 1000000$, and therefore quite sufficient in point of extent to embrace all the variety of colours the eye can distinguish. The number of tints recognised as distinct by the Roman artists in Mosaic is said to exceed 30,000; but if we suppose ten times this amount to occur in nature (and it is obvious that these must be greatly more numerous than the purposes of the painter admit) we are still much within the limits of our scale. It only remains to examine how far the tints themselves are expressible by the members of the scale proposed.

511. **Whites, greys, and neutral tints.** And first, then, of whites, greys, and neutral tints. The most perfectly neutral tints, which are, in fact, only greater and less intensities of whiteness, are those we observe in the clouds in an ordinary cloudy day, with occasional gleams of sunshine. From the most sombre shadows to the snowy whiteness of those cumulus-shaped clouds on which the sun immediately shines, we have nothing but a series of whites, or greys, represented by such combinations as $\mathrm{R} + \mathrm{Y} + \mathrm{B}$, $2\,\mathrm{R} + 2\,\mathrm{Y} + 2\,\mathrm{B}$, &c.; or $n\,(\mathrm{R} + \mathrm{Y} + \mathrm{B})$ which, for brevity, we may represent by $n\,\mathrm{W}$. To be satisfied of this we need only look through a tube blackened on the inside to prevent surrounding objects influencing our judgments; and any small portion thus insulated of the darkest clouds will appear to differ in no respect from a portion similarly insulated of a sheet of white paper more or less shaded.

512. **Reds, yellows, and blues.** The various intensities of pure reds, yellows, and blues are represented by $n\,\mathrm{R}$, $n\,\mathrm{Y}$, and $n\,\mathrm{B}$ respectively. They are rare in nature; but blood, fresh gilding, or gamboge moistened, and ultramarine may be cited as examples of them. Scarlets and vivid reds, such as vermilion and minium, are not free from a mixture of yellow, and even of blue; for all the primary colours are greatly increased in splendour by a certain mixture of white, and whenever any primary colour is peculiarly glaring and vivid, we may be sure that it is in some degree diluted with white. The blue of the sky is white, with a very moderate addition of blue.

513. The mixture of red and yellow produces all the shades of scarlet, orange, and the deeper browns, when of feeble intensity. When diluted with white, we have lemon colour, straw colour, clay colour, and all the brighter browns; the last-mentioned tints growing duskier and dingier as the coefficients are smaller.

514. **Browns.** The browns, however, are essentially sombre tints, and produce their effects chiefly by contrast with other brighter hues in their neighbourhood. To produce a brown, the painter mixes black and yellow, or black and red, (that is, such impure reds as the generality of red pigments,) or all three; his object is to stifle light, and leave only a residuum of colour. There is a brown glass very common in modern ornamental windows. If examined with a prism, it is found to transmit the red, orange, and yellow rays abundantly, little green, and no pure blue. The small quantity of blue, then, that its tint does involve, must be that which enters as a component part of its green, (in this view of the composition of colours,) and its characteristic symbol may thus be, perhaps, of some such form as $10\,\mathrm{R} + 9\,\mathrm{Y} + 1\,\mathrm{B}$; that is to say, $(9\,\mathrm{R} + 8\,\mathrm{Y}) + 1\,(\mathrm{R} + \mathrm{Y} + \mathrm{B})$, or an orange of the character $9\,\mathrm{R} + 8\,\mathrm{Y}$ diluted with one ray of white. It must be confessed, however, that the composition of brown tints is the least satisfactory of all the applications of Mayer's doctrine. He himself has passed it unnoticed.

515. **Purples.** Combinations of red and blue, and their dilutions with white, form all the varieties of crimson, purple, violet, rose colour, pink, &c. The richer purples are entirely free from yellow. The prismatic violet, when compared with the indigo, produces a sensible impression of redness, and must therefore be regarded on this hypothesis as consisting of a mixture of blue and red rays.

516. **Greens.** Blue and yellow, combined, produce green. The green thus arising is vivid and rich; and, when proper proportions of the elementary colours are used, no way to be distinguished from the prismatic green. Nothing can be more striking, and even surprising, than the effect of mixing together a blue and a yellow powder, or of covering a paper with blue and yellow lines, drawn close together, and alternating with each other. The elementary tints totally disappear, and cannot even be recalled by the imagination. One of the most marked facts in favour of the idea of the existence of three primary colours, and of the possibility of an analysis of white light distinct from that afforded by the prism, is to see the prismatic green thus completely imitated by a mixture of adjacent rays totally distinct from it, both in refrangibility and colour.

517. **The same colour produced by different prismatic combinations.** The hypothesis of three primary colours, of which, in different proportions, all the colours of the spectrum are composed, affords an easy explanation of a phenomenon observed by Newton, viz. that tints no way distinguishable from each other may be compounded by very different mixtures of the seven colours into which he divided it. Thus we may regard white light, indifferently, as composed of

$$\left.\begin{array}{l} \mathrm{R} = a + b + c \text{ rays of pure red} \\ \mathrm{Y} = d + e + f + g \text{ rays of pure yellow} \\ \mathrm{B} = h + i + k + l \text{ rays of pure blue} \end{array}\right\} \text{or of} \left\{\begin{array}{l} b \text{ rays of pure red} = \mathrm{R}' \\ c + d \text{ rays of orange } (c \text{ red} + d \text{ yellow}) = \mathrm{O}' \\ e \text{ rays of pure yellow} = \mathrm{Y}' \\ f + h \text{ rays of green } (f \text{ yellow} + h \text{ blue}) = \mathrm{G}' \\ g + i \text{ rays of prismatic blue } (g \text{ yellow} + i \text{ blue}) = \mathrm{B}' \\ k \text{ rays of indigo, or pure blue} = \mathrm{I}' \\ l + a \text{ rays of violet } (l \text{ blue} + a \text{ red}) = \mathrm{V}' \end{array}\right.$$

and any tint capable of being represented by $x \,.\, R + y \,.\, Y + z\, B$, may be represented equally well by

$$m \,.\, R' + n \,.\, O' + p \,.\, Y' + q \,.\, G' + r \,.\, B' + s \,.\, I' + t \,.\, V',$$

provided we assume m, n, p, &c., such as to satisfy the equations

$$m b + n c + t a = x; \quad n d + p e + q f + r g = y; \quad q h + r i + s k + t l = z.$$

518. Dr. Young's hypothesis of three other primary colours.

From what has been said we shall now proceed to show, that, without departing from Mayer's doctrine, any other three prismatic rays may still be equally assumed as fundamental colours, and all the rest compounded from them, provided we attend only to the predominant tint resulting, and disregard its dilution with white. For instance, Dr. Young has assumed red, green, and violet as his fundamental colours; and states, as an experimental fact in support of this doctrine, that the perfect sensations of yellow and blue may be produced, the former by a mixture of red and green, and the latter by green and violet. (*Lectures on Natural Philosophy*, p. 439.) Now, if we mix together yellow and white in the proportion of m yellow + n white, the compound will produce a perfect sensation of yellow, unless m be small compared to n; but, assuming white to be composed as above, this compound is equivalent to

$$n\,R \text{ red} + (m + n)\, Y \text{ yellow} + n\, B \text{ blue}.$$

On the other hand, if we mix together P such red rays (each of the intensity b) and Q such green rays (each consisting of yellow, of the intensity f, and blue of the intensity h) as are supposed in the foregoing article to exist in the spectrum, we have a compound of

$$P \,.\, b \text{ red} + Q \,.\, f \text{ yellow} + Q \,.\, h \text{ blue},$$

and these will be identical with the former, if we take

$$n\,R = P\,b; \quad (m + n)\, Y = Q\,f; \quad n\,B = Q\,h.$$

Eliminating Q from the two last of these, we get

$$\frac{m}{n} = \frac{f}{h} \,.\, \frac{B}{Y} - 1$$

for the relation between M and N. Now the only conditions to be satisfied are that M shall be positive, and not much less than N; and it is evident that these conditions may be fulfilled an infinite number of ways by a proper assumption of the ratio of f to h. In the same manner, if we suppose a mixture of M rays primary blue = B with N rays of white (= R + Y + B) to be equivalent to P rays of prismatic green mixed with Q of violet, we get the equation

$$\frac{m}{n} = \frac{l}{a} \,.\, \frac{R}{B} + \frac{h}{f} \quad \frac{Y}{B} - 1.$$

519. Numerical illustration.

Suppose, for example, we regard white light as consisting of 20 rays of primary red, 30 of yellow, and 50 of blue, and the several prismatic rays to consist as follows:

Red 8 rays primary red = h.
Orange 7 .... red + 7 primary yellow = $c + d$.
Yellow 8 .... yellow = e.
Green 10 .... yellow + 10 primary blue = $f + h$.
Blue 6 .... yellow + 12 primary blue = $g + i$.
Indigo 12 .... blue = k.
Violet 16 .... blue + 5 primary red = $l + a$.

Then will the union of 15 rays of such red with 30 of such green, produce a compound ray containing 15 × 8 = 120 of primary red, 30 × 10 = 300 of primary yellow, and 30 × 10 = 300 of primary blue; which are the same as exist in a yellow, consisting of 6 rays of white combined with 4 of primary yellow. In like manner, if 75 such green rays be combined with 100 such violet, the result will be 100 × 5 = 500 rays of primary red, + 75 × 10 = 750 of primary yellow, + 75 × 10 + 100 × 16 = 2350 of primary blue, which together compose a tint identical with that which would result from the union of 25 rays of white with 22 of primary blue; that is to say, a fine lively blue. The numbers assumed above, it must be understood, are merely taken for the sake of illustration, and are no way intended to represent the true ratios of the differently coloured rays in the spectrum.

520. Phenomena of coloured flames

The analogy of the fixed lines in the solar spectrum might lead us to look for similar phenomena in other sources of light. Accordingly, Fraunhofer has found, that each fixed star has its own particular system of dark and bright spaces in its spectrum; but the most curious phenomena are those presented by coloured flames, which produce spectra (when transmitted through a colourless prism) hardly less capricious than those afforded by solar light transmitted through coloured glasses. Dr. Brewster, Mr. Talbot, and others, have examined these phenomena with attention; but the subject is not exhausted, and promises a wide field of curious research. The following facts may be easily verified:

521. Flames of combustibles burning feebly.

1. Most combustible bodies consisting of hydrogen and carbon, as tallow, oil, paper, alcohol, &c. when first lighted and in a state of feeble and imperfect combustion, give blue flames. These, when examined by the prism, by letting them shine through very narrow slits parallel to its edge, as described in Art. 487, all give interrupted spectra, consisting, for the most part, of narrow lines of very definite refrangibility, either separated by broad spaces entirely dark, or much more obscure than the rest. The more prominent rays are, a very narrow definite yellow, a yellowish green, a vivid emerald green, a faint blue, and a strong and copious violet.

522. Burning strongly.

2. In certain cases when the combustion is violent, as in the case of an oil lamp urged by a blow-pipe, (according to Fraunhofer,) or in the upper part of the flame of a spirit lamp, or when sulphur is thrown into a white-hot crucible, a very large quantity of a definite and purely homogeneous yellow light is produced; and in the latter case forms nearly the whole of the light. Dr. Brewster has also found the same yellow light to be produced when spirit of wine, diluted with water and heated, is set on fire; and has proposed this as a means of obtaining a supply of homogeneous yellow light for optical experiments.

523. Flames coloured by saline bodies.

3. Most saline bodies have the power of imparting a peculiar colour to flames in which they are present, either in a solid or vaporous state. This may be shown in a manner at once the most familiar and most efficacious, by the following simple process: Take a piece of packthread, or a cotton thread, which (to free it from saline particles should have been boiled in clean water,) and having wetted it, take up on it a little of the salt to be examined in fine powder, or in solution. Then dip the wetted end of it into the cup of a burning wax candle, and apply it to the exterior of the flame, not quite in contact with the luminous part, but so as to be immersed in the cone of invisible but intensely-heated air which envelopes it. Immediately an irregular sputtering combustion of the wax on the thread will take place, and the invisible cone of heat will be rendered luminous, with that particular coloured light which characterises the saline matter employed.

524. The colour depends chiefly on the base.

Thus it will be found that, in general,

Salts of soda give a copious and purely homogeneous yellow.
Salts of potash give a beautiful pale violet.
Salts of lime give a brick red, in whose spectrum a yellow and a bright green line are seen.
Salts of strontia give a magnificent crimson. If analyzed by the prism two definite yellows are seen, one of which verges strongly to orange.
Salts of magnesia give no colour.
Salts of lithia give a red, (on the authority of Dr. Turner's experiments with the blow-pipe.)
Salts of baryta give a fine pale apple-green. This contrast between the flames of baryta and strontia is extremely remarkable.
Salts of copper give a superb green, or blue green.
Salt of iron (protoxide) gave white, where the sulphate was used.

Of all salts, the muriates succeed best, from their volatility. The same colours are exhibited also when any of the salts in question are put (in powder) into the wick of a spirit lamp. If common salt be used, Mr. Talbot has shown that the light of the flame is an absolutely homogeneous yellow; and, being at the same time very copious, this property affords an invaluable resource in optical experiments, from the great ease with which it is obtained, and its identity at all times. The colours thus communicated by the different bases to flame, afford in many cases a ready and neat way of detecting extremely minute quantities of them; but this rather belongs to Chemistry than to our present subject. The pure earths, when violently heated, as has recently been practised by Lieutenant Drummond, by directing on small spheres of them the flames of several spirit lamps urged by oxygen gas, yield from their surfaces lights of extraordinary splendour, which, when examined by prismatic analysis, are found to possess the peculiar definite rays in excess, which characterise the tints of flames coloured by them; so that there can be no doubt that these tints arise from the molecules of the colouring matter reduced to vapour, and held in a state of violent ignition.

527. It is the 7th and 8th of these assumptions only which render the course pursued by a luminous molecule, under the influence of the reflective or refractive forces, capable of being reduced to mathematical calculation; for it follows immediately from the 8th, that, up to the very moment when such a molecule arrives in physical contact with the surface of any medium, it is acted on by no sensible force, and therefore not sensibly deviated from its rectilinear path; and, on the other hand, as soon as it has penetrated to any sensible depth within the surface, or among the molecules, by reason of the 7th of the above postulates, it must be equally attracted and repelled by them in all directions, and therefore will continue to move in a right line, as if under the influence of no force. It is only, therefore, within that insensible distance on either side the surface, which is measured by the diameter of the sphere of action of each molecule, that the whole flexure of the ray takes place. Its trajectory then may be regarded as a kind of hyperbolic curve, in which the right lines described by it, previous and subsequent to its arrival at the surface, are the infinite branches, and are confounded with the asymptotes, and the curvilinear portion is concentered as it were in a physical point. Now, in explaining the phenomena of reflexion and refraction, it is not the nature of this curve that we are called on to investigate. This will depend on the laws of corpuscular action, and must necessarily be of great complexity. All we have to inquire, is the *direction* the ray will ultimately take after incidence, and the final change, if any, in its velocity.

528. Motion of a luminous molecule under the influence of any forces.

Let us, then, consider the motion of a molecule urged to or from the surface of a medium by the united attractions or repulsions of all its particles acting according to any conceivable mathematical law. And, first, it is evident, that supposing the surface mathematically smooth, and the number of attractive or repulsive particles of which it consists, infinite, their total resultant force on the luminous molecule will act in a direction perpendicular to the surface; and will be insensible at all sensible distances from the surface, provided the elementary forces of each molecule decrease with sufficiently great rapidity as the distances increase. This condition being supposed, let x and y be the coordinates of the molecule at any assigned instant; the plane of the x and y being supposed to coincide with that of its trajectory, out of which plane there is evidently no force to turn it, and which must of course be perpendicular to the surface of the medium in which x is supposed to lie: y then will be the perpendicular distance of the luminous molecule from this surface, and Y (some function of y decreasing with extreme rapidity) will represent the force urging it inwards, or *towards* the surface when the molecule is without, *from* when within the medium. Therefore, by the principles of Dynamics, supposing $d\,t$ to denote the element of the time, we shall have for the equations of the motion

$$\frac{d^2 x}{d t^2} = 0; \qquad \frac{d^2 y}{d t^2} + \mathrm{Y} = 0; \qquad (a)$$

and hence, multiplying the first by $d x$, the second by $d y$, adding and integrating, we get

$$\frac{d x^2 + d y^2}{d t^2} + 2 \int \mathrm{Y}\, d y = \text{constant}.$$

Now, v being the velocity of the molecule, we have $v^2 = \dfrac{d x^2 + d y^2}{d t^2}$, and therefore this equation becomes

$$v^2 = \text{constant} - 2 \int \mathrm{Y}\, d y.$$

It is, however, only with the terminal velocity, or that attained by the light after undergoing the total action of the medium, that we are concerned, and therefore if we put V for its primitive, or initial, and V′ for its terminal velocity, we shall have, by extending the integral from the value of y at the commencement of the ray's motion (y_0) to its value at the end $(y_{\prime})$,

$$\mathrm{V}'^2 - \mathrm{V}^2 = -2 \int \mathrm{Y}\, d y. \qquad (b)$$

Since y_0 and $y_{\prime}$ are supposed infinite, and since the function Y decreases by hypothesis with such rapidity as to become absolutely insensible for all sensible values of y, it is clear that we may take $y_0 = + \infty$ for the first limit of the integral in all cases. With regard to the other, we have now to distinguish two principal cases:

529. Case of reflexion.

The first is that of *reflexion*, where the ray, no matter whether before its arrival at the surface, or at reaching it, or even after passing some small distance into the medium, is turned back by the prevalence of the repulsive force, and pursues the whole of its course afterwards without the medium. Now in this case if we resolve the integral $\int \mathrm{Y}\, d y$ into its elements, these, in the approach of the molecule to the surface, may be represented as follows,

$$\&\text{c.} + \mathrm{Y}' \times - d y + \mathrm{Y}'' \times - d y + \mathrm{Y}''' \times - d y + \&\text{c.}$$

But in the recess of the molecule, the values of y increase again by the same steps as they before diminished and become identical with the former ones; and Y′, Y″, &c., the values of Y corresponding to the successive values of y, remain therefore the same, both in size and magnitude; the corresponding elements of the integral generated during the recess of the molecule will be then

$$\&\text{c.} + \mathrm{Y}' \times + d y + \mathrm{Y}'' \times + d y + \mathrm{Y}''' \times + d y + \&\text{c.}$$

$\frac{(\text{refractive index})^2 - 1}{\text{specific gravity}}$. Such is Newton's idea of the *refractive power* of a medium as differing from its refractive *index*. It rests, however, on a purely hypothetical assumption, that of the similarity of *form* of the law of force for all media, respecting which we can be said to know nothing whatever. For a table of its values for different media, see the Collection of Tables at the end of this Essay.

536. Principle of least action employed. The constancy of the ratio of the sines of incidence and refraction has here been derived by direct integration of the fundamental equations. There is, however, another mode of deducing this important law, much more circuitous, it is true, in this simple case, but which offers peculiar advantages in the more complicated ones of double refraction; and which, therefore we shall here explain, to familiarize the reader beforehand with its principle and mode of application. It consists in the employment of what is called, in Dynamics, the *principle of least action*, in virtue of which the sum of each element of the trajectory described by any moving molecule multiplied by the velocity of its description (or the integral $\int v\, d\, s$) is a minimum when taken between any two fixed points in the trajectory. The trajectory described by any luminous molecule may be regarded as consisting of two rectilineal portions, or hyperbolic branches, confounded with their asymptotes, and one curvilinear one concentrated in a space of insensible magnitude, a physical point. Within this *point* the whole operation of the flexure of the ray, however complicated, is performed; and *here* the velocity is variable. In the branches it is uniform. Suppose, then, A and B to be any two fixed points in these, taken as points of departure and arrival of a ray, and let C be the point in the surface of a reflecting or refracting medium where the flexure takes place, and suppose A C = S, B C = S′ and let σ be the excessively minute curvilinear portion of the ray at C, and v the variable velocity with which it is described, V and V′ being those with which S and S′ are described. Then may the integral $\int v\, d\, s$ be resolved into the three portions $\int \mathrm{V}\, d\, \mathrm{S} + \int v\, d\, \sigma + \int \mathrm{V}'\, d\, \mathrm{S}'$. Of these the second is utterly insensible, by reason of the minuteness of σ, and the other two, since V and V′ are constant, become merely $\mathrm{V}\,.\,\mathrm{S} + \mathrm{V}'\,.\,\mathrm{S}'$.

537. The position of C, then, with respect to A and B, will be determined by the condition $\mathrm{V}\,.\,\mathrm{S} + \mathrm{V}'\,.\,\mathrm{S}' =$ a minimum, A and B being supposed fixed, and C any how variable on the surface. Now, in the case before us, V the velocity of the light before, and V′ that after incidence, are *both*, as we showed in Article 529 and 530, independent of the direction of the incident and reflected or refracted rays, or of the position of C; and, therefore, are to be considered as absolute constants in this problem of minima, which is thus reduced to a simple geometrical question. Given A and B to find C, a point in a given plane, such that V (= constant) × A C + V′ (= constant) × B C shall be a minimum. Nothing is easier than the solution. Put a, b, c, a', b', c' for the respective coordinates of A and B, and x, y, o for that of C, taking the given plane for that of the x, y.

Solution of the geometrical problem of the minimum. Then

$$\mathrm{V}\,.\,\mathrm{S} + \mathrm{V}'\,.\,\mathrm{S}'\,. = \mathrm{V}\,.\,\sqrt{(x-a)^2 + (y-b)^2 + c^2} + \mathrm{V}'\,.\,\sqrt{(x-a')^2 + (y-b')^2 + c'^2}$$

is to be a minimum by the variation of x and y, independent of each other. This gives, by differentiation,

$$\frac{\mathrm{V}}{\mathrm{S}}\left\{(a-x)\,d\,x + (b-y)\,d\,y\right\} + \frac{\mathrm{V}'}{\mathrm{S}'}\left\{(a'-x)\,d\,x + (b'-y)\,d\,y\right\} = 0;$$

and this, since x and y are independent, must vanish, whatever values are assigned to $d\,x$ and $d\,y$, therefore we must have separately

$$\frac{\mathrm{V}}{\mathrm{S}}(a-x) + \frac{\mathrm{V}'}{\mathrm{S}'}(a'-x) = 0; \qquad \frac{\mathrm{V}}{\mathrm{S}}(b-y) + \frac{\mathrm{V}'}{\mathrm{S}'}(b'-y) = 0. \qquad (d)$$

These give, respectively,

$$\frac{\mathrm{S}'}{\mathrm{S}} = -\frac{\mathrm{V}'}{\mathrm{V}}\,.\,\frac{a-x}{a-x}; \qquad \frac{\mathrm{S}'}{\mathrm{S}} = -\frac{\mathrm{V}'}{\mathrm{V}}\,.\,\frac{b'-y}{b-y};$$

by equating which we get

$$(a'-x)\,(b-y) = (b'-y)\,(a-x);$$

or multiplying out and reducing

$$y = x\,.\,\frac{b-b'}{a-a'} + \frac{a\,b' - b\,a'}{a-a'};$$

and, consequently,

$$b'-y = \frac{b-b'}{a-a'}\,(a'-x)$$

This equation expresses, that the two portions S and S′ of the ray before and after incidence on the surface at C both lie in one plane, and that this plane is perpendicular to the surface, or to the plane of the coordinates x, y.

538. Constancy of the ratio of the sines deduced. Again, if we resume the equations (d) and putting them under the form

$$\mathrm{S}'\,(a-x) = -\frac{\mathrm{V}'}{\mathrm{V}}\,\mathrm{S}\,(a'-x); \qquad \mathrm{S}'\,(b-y) = -\frac{\mathrm{V}'}{\mathrm{V}}\,(b'-y)\,.\,\mathrm{S}.$$

Square and add them we get

now being all equal to what they were before, but acting in a contrary direction with respect to the motion of the molecule, it will describe a portion C d' c' b' a' B similar, and equal to the portion on the other side of C. This is the case of reflexion. But suppose, as in fig. 120, the ray to have such an initial velocity of approach, or the repulsive forces to be so feeble, compared to the attractive, that before its whole velocity perpendicular to the surface is destroyed, it shall have passed through all the strata of attraction and repulsion, and entered the region where the forces of all the molecules are in equilibrium, as at e. In this case the remainder of its course will be rectilinear, and wholly within the medium. This is the case of refraction. In both cases, it is the final course it takes, or the direction of the asymptotic branches a' B or e B, about which only we have any knowledge; of the number and nature of the undulations of its course between a and a', or e, we know nothing.

542. Motion of a ray at common surface of two media.

The whole of this reasoning applies equally to the motion of a luminous molecule at the confines of two media, as at the surface separating one medium from a vacuum. The molecules of either medium being supposed *uniformly distributed*, and *acting equally in all directions around them*, the resultant of all their forces on the luminous particle must be perpendicular to the common surface, which is all that is required in the foregoing theory.

543. Newtonian idea of a ray of light as composed of a succession of molecules.

In the Corpuscular doctrine, a ray of light is understood to mean a continued succession or stream of molecules, all moving with the same velocity along one right line, and following each other close enough to keep the retina in a constant state of stimulus, i. e. so fast, that before the impression produced by one can have time to subside another shall arrive. It appears, by experiment, that to produce a continued sensation of light, it is sufficient to repeat a momentary flash about 8 or 10 times in a second. If a red-hot coal on the point of a burning stick be whirled round, so as to describe a circle, and the velocity of rotation be greater than 8 or 10 circumferences per second, the eye can no longer distinguish the place of the luminous point at any instant, and the whole circle appears equally bright and entire. This shows, evidently, that the sensation excited by the light falling on any one point of the retina, must remain almost without diminution till the impression is repeated during the subsequent revolution of the luminary. Now, if uninterrupted vision can be produced by momentary impressions, repeated at intervals so distant as a tenth of a second, it is easy to conceive that the individual molecules of light in a ray will not require to follow close on each other to affect our organs with a continued sense of light. As their velocity is nearly 200,000 miles per second, if they follow each other at intervals of 1000 miles apart, 200 of them would still reach our retina per second, in every ray. This consideration frees us from all difficulties on the score of their jostling, or disturbing each other in space, and allows of infinite rays crossing at once through the same point of space without at all interfering with each other, especially when we consider the minuteness which must be attributed to them, that (moving with such swiftness) they should not injure our organs. If a molecule of light weighed but a single grain, its inertia would equal that of a cannon ball of upwards of 150 pounds weight, moving at the rate of 1000 feet per second. What then must be their tenuity, when the concentration of millions upon millions of them, by lenses or mirrors, has never been found to produce the slightest mechanical effect on the most delicately contrived mechanism, in experiments made expressly to detect it. (See Mr. Bennet's *Experiments*, *Phil Trans.* 1792, vol. lxxxii. p. 87.)

Their distance *inter se.*

Their extreme tenuity illustrated.

544. Partial reflexion explained on Newton's principles.

When a ray of light falls on a reflecting or refracting surface, since all its molecules move with equal velocity and are incident in the same line, it would seem that whatever took place with one should equally happen to all; and that, if the first underwent reflexion, all should do so; while, on the other hand, if one could penetrate the surface, and pursue its course entirely within the medium, all ought to do the same. This, however, is contrary to experience; as whenever a ray of light is incident on the exterior surface of any medium, a part only is reflected, and the rest enters the medium. No theory can be satisfactory which does not render a good account of so principal a fact. The Newtonian doctrine accounts for it by the fits of easy reflexion and transmission. To understand this explanation we must recur to the ninth postulate, (Art. 526,) and suppose two molecules to arrive at the surface under the same incidence, the one in a fit of easy reflexion, the other in one of easy transmission. The former will then be more affected by the repulsive forces, the latter by the attractive of the molecules of the medium; and hence it is evident, that the one may be reflected under circumstances of incidence, &c. in which the other will penetrate the surface and be refracted. Now it will depend entirely on the nature of the medium, and the initial velocity of a luminous molecule *towards* it, (which is as the cosine of the angle of incidence,) whether it will require the whole exertion of its repulsive forces, in their most energetic manner, to destroy that velocity and produce reflexion, or only a part of them. In the former case only such molecules as arrive *in the most favourable* disposition to be reflected, or in the most intense phase of a fit of easy reflexion, can be reflected. In the latter, such as arrive in less favourable dispositions, or *in less intense phases* of fits of reflexion, may be reflected; and if the repulsive forces of the medium be very intense, in comparison with the attractive ones, or if the obliquity of incidence be so great as to give the molecule a very small velocity perpendicular to the surface, even those molecules which arrive in the less energetic phases of fits of easy transmission may still be unable to penetrate the strata of repulsion.

545. Reflexion more copious at great obliquities.

Hence, then, we see that the proportion of the molecules of a ray falling on the surface of a medium in every possible state or phase of their fits, which undergo reflexion, will depend, first, on the nature of the medium on whose surface they fall, or if it be the common surface of two, then on both; secondly, on the angle of incidence. At great obliquities, the reflexion will be more copious; but even at the greatest, when the incident ray just grazes the surface, it by no means follows that every molecule, or even the greater part, *must* be reflected. Those which arrive in the most favourable phases of their fits of transmission, will obey the influence of small attractive forces, in preference to strong repulsive ones; but it will depend entirely on the nature of the media whether the former or the latter shall prevail, the fits in the Newtonian doctrine being conceived only to *dispose* the luminous molecules, other circumstances being favourable, to reflexion or transmission; to exalt the forces which tend to produce the one and to depress those which act in favour of the other, but not to determine, absolutely, its reflexion or transmission under all circumstances.

546. Confirmed by experiment. These conclusions are verified by experience. It is observed, that the reflexion from the surfaces of transparent (or indeed any) media, becomes sensibly more copious as the angle of incidence increases; but at the *external* surface of a single medium is never total, or nearly total. In glass, for instance, even at extreme obliquities, a very large portion of the light still enters the glass and undergoes refraction. In opaque media, such as polished metals, the same holds good; the reflexion increases in vividness as the incidence increases, but never becomes total, or nearly so. The only difference is, that here the portion which penetrates the surface is instantly absorbed and stifled.

547. Reflexion at common surface of two media. The phenomena which take place when light is reflected at the common surface of two media, are such as from the above theory we might be led to expect,—with the addition, however, of some circumstances which lead us to limit the generality of our assumptions, and tend to establish a relation between the attractive and repulsive forces, to which the refraction and reflexion of light are supposed to be owing. For it is found, that when two media are placed in perfect contact, (such as that of a fluid with a solid, or of two fluids with one another,) the intensity of reflexion at their common surface is always less, the nearer the refractive indices of the media approach to equality; and when they are exactly equal, reflexion ceases altogether, and the ray pursues its course in the second medium, unchanged either in direction, velocity, or intensity. It is evident, from this fact, which is general, that the reflective or refractive forces, in all media of equal refractive densities, follow exactly the same laws, and are similarly related to one another; and that in media unequally refractive, the relation between the reflecting and refracting forces is not arbitrary, but that the one is dependent on the other, and increases and diminishes with it. This remarkable circumstance renders the supposition made in Art. 535, of the identity of form of the function Y, or $\phi\ (y)$ expressing the law of action of the molecules of all bodies on light indifferently, less improbable.

548. Phenomena exhibited experimentally. To show experimentally the phenomena in question, take a glass prism, or thin wedge of very small refracting angle (half a degree, for instance: almost any fragment of plate glass, indeed, will do, as it is seldom the two sides are parallel,) and placing it conveniently with the eye close to it, view the image of a candle reflected from the exterior of the face next the eye. This will be seen accompanied at a little distance by another image, reflected internally from the other face, and the two images will be nearly of equal brightness, if the incidence be not very great. Now, apply a little water, or a wet finger, or, still better, any black substance wetted, to the posterior face, at the spot where the internal reflexion takes place, and the second image will immediately lose great part of its brightness. If olive oil be applied instead of water, the defalcation of light will be much greater; and if the substance applied be pitch, softened by heat, so as to make it adhere, the second image will be totally obliterated. On the other hand, if we apply substances of a higher refractive power than glass, the second image again appears. Thus, with oil of cassia it is considerably bright; with sulphur, it cannot be distinguished from that reflected at the first surface; and if we apply mercury, or amalgam, (as in a silvered looking-glass,) the reflexion at the common surface of the glass and metal is much more vivid than that reflected from the glass alone.

549. Phenomena depending on the foregoing principles. The destruction of reflexion at the common surface of two media of equal refractive powers explains many curious phenomena. If we immerse an irregular fragment of a colourless transparent body (as crown glass) in a colourless fluid of precisely equal refractive power, it disappears altogether. In fact, the surface being only visible by the rays reflected from it; destroy this reflexion, and the object must cease to be seen, unless from any opacity in its substance reflecting rays from its interior, which is not here contemplated. Hence, if the powder of any such substance be moistened with a fluid of the same refractive density, all the internal and external reflexions at the surfaces of the small fragments of which it consists, which, blended and confused, present the general appearance of a white opaque mass, will be destroyed, and the powder will be rendered perfectly transparent. Transparency of oiled paper. A familiar instance of this nature is the transparency given to paper by moistening it with water, or, still better, with oil; paper is composed of an infinity of minute transparent, or nearly transparent fibres of a ligneous substance, having a refractive power probably not very different from some of the more refractive oils. Its whiteness is caused by the confused reflexion of the incident rays at all possible angles, both internally and externally, those which have escaped reflexion at one fibre, undergoing it among those beneath. If moistened with any liquid, the intensity of these reflexions is weakened, and the more the more nearly its refractive power approaches to that of the paper itself; so that a considerable number of rays find their way through it, and emerge at the posterior surface. The transparency acquired by the hydrophane, by immersion in water, is, no doubt, owing to this cause; the water filling up the minute pores, and enfeebling the internal reflexion; and Dr. Brewster, in a very curious and interesting Paper on the tabasheer, (a siliceous concretion found in sugar-canes, and the lowest in the scale of refracting powers among solids,) has explained on this principle a number of extraordinary phenomena exhibited on moistening that substance with various liquids, (see *Philosophical Transactions*, 1819.)

550. Total internal reflexion. The reasoning of Art. 529 applies, it is evident, equally to the case when a ray is reflected from the interior surface of a dense medium placed in air, and when from the exterior. The only difference is, that in the latter case the reflexion is performed by the action of repulsive, and in the former by that of attractive forces. The course of a ray internally reflected may be conceived, as in fig. 121 and 122; and the reflexion may take place in any of the attractive regions, or laminæ, whether within or without the true surface, i. e. the last layer of molecules which constitute the medium. There is one case of internal reflexion, however, too remarkable to be passed without more particular notice. It is, that when the interior angle of incidence exceeds the *limiting angle* whose sine is $\frac{1}{\mu}$, (see Art. 183 *et seq.*;) and when, as we there stated, as a result of experiment, the

internal reflexion is *total*. To see how this happens, let us consider a ray incident exactly at this angle, and in the most intense phase of its fit of transmission. Then will it be refracted; and, since the angle of refraction must be just 90°, (by reason of the generality of the demonstration of the law of refraction in Art. 529,) it will emerge, grazing the surface, exactly at the extreme boundary of the outermost region C B, (fig. 123,) where all sensible action ceases. Its initial velocity under these circumstances in the direction perpendicularly to the surface, is barely sufficient to carry it up to this extreme limit, where it is quite annihilated. If, then, we conceive another ray, also incident in the most intense phase of its fit of transmission, but at an angle more oblique by an infinitely small quantity, then, since its initial velocity at right angles to the surface is less, it will be destroyed before it has quite reached this limit, and the ray will therefore begin to move parallel to the surface, just *within* the last limit to the sphere of its action.

551. The outermost sphere of action necessarily attractive.

Now the last action which the surface exerts, or that force which extends to the greatest distance from it, cannot be otherwise than attractive; for, first, were it repulsive, it is evident that no ray incident externally at an extreme incidence, (i. e. approaching indefinitely to 90°,) could by possibility escape reflexion; and, secondly, no ray on that supposition could emerge from within the medium, without having at its emergence an obliquity to the surface greater than some finite angle, the last action of the medium being in this case to bend it *outwards*, both which consequences are contrary to fact. Or we may consider the point thus, Since a ray incident within, at the limiting angle, emerges, if it emerge at all, parallel to the surface; and since every point in the curve described by it previous to the instant of emergence is nearer to the medium than the line of its ultimate direction, it is geometrically impossible that the curvature immediately adjacent to the point of emergence should be otherwise than *concave* towards the medium; and must, therefore, of necessity be produced by a force directed *to* it, i. e. an attractive one.

552. Hence, the luminous molecule we have been considering, will be within the attractive region at the moment when its perpendicular motion is destroyed; it will, therefore, be turned inwards, as at the dotted line fig. 123, and be reflected. *A fortiori*, therefore, will every molecule incident in a less intense phase of a fit of transmission, or in one of reflexion, as well as every one incident at a more oblique incidence, i. e. with a less initial perpendicular velocity, be reflected. Those in which the circumstances are most favourable to transmission will reach the exterior attractive region, as in fig. 123. Others in which they are less so will be reflected in some intermediate region, as in fig. 122, while those which are incident at extreme internal obliquities, or in the most intense phases of fits of reflexion, will have their courses as represented in fig. 121.

553. Fact respecting oblique reflexion from water.

The conclusion at which we have arrived in the last Art. that the attractive force of a medium on the molecules of light extends to a greater distance than the repulsive, is, as we have seen, a necessary consequence of dynamical principles; and so far from being in opposition to Newton's doctrine of reflexion, as has been said, is in perfect accordance with it. Dr. Brewster has been led to the same conclusion by peculiar considerations grounded on his experiments on the law of polarization, (*Phil. Trans.*, 1815, p. 133,) and has applied it to explain a curious fact noticed by Bouguer, viz. that although water be much less reflective than glass at small incidences, yet at great ones (as $87^\circ\frac{1}{2}$) it is much more so. Now, supposing the light to have undergone *the whole effect* of the refracting forces, in both cases before it suffers reflexion, its incidence, when it reaches the region of the repulsive forces, will have been diminished in the case of glass, to 57° 44′, but in that of water only to 61° 5′, and therefore being incident more obliquely on the water it ought to be more copiously reflected. Whatever we may think of the validity of this explanation, it is certainly ingenious, and the fact extremely remarkable, and deserving of all attention.

554. Experiment showing the phenomena of total reflexion.

To see the phenomena of total reflexion to the best advantage, lay down a right-angled glass prism on a black substance close to a window, with its base horizontal, as in fig. 124, and apply the eye close to the side, looking downwards. The base will be seen divided into two portions, by a beautiful coloured arch like a rainbow concave to the eye, the portion above the arch being extremely brilliant and vivid, and giving a reflexion of all external objects no way to be distinguished from reality. On the other hand, the space within the concavity of the bow is comparatively sombre, the reflexion of the clouds, &c. on that part of the base being much less vivid. If, instead of placing it on a black body, we hold it in the hand, and place a candle *below* it, this will be visible; but (wherever placed) will always appear in some part of the base within the concavity of the bow. Fig. 124 represents the course of the rays in this experiment, E being the eye, N G, O F, P D rays incident through the farther side at various angles of obliquity on the base, and reflected to the eye at E, of which O F is incident precisely at the limiting angle. It is obvious, that all the rays towards N incident on that part of the base beyond F being too oblique for transmission will be totally reflected, while those incident between F and A, being less oblique than is required for total reflexion, will be only partially so, a portion escaping through the base in the direction D Q. Again, if we place a luminary at any point as L below the base, it is manifest that to reach the eye, a ray from it must fall between A and F, as L D, and that no ray falling on any part of the base between B and F can be refracted to E.

555. Reflected prismatic bow.

The coloured arch separating the region of total from that of partial reflexion, is thus explained. For, simplicity, let us suppose the eye within the medium, (to avoid considering the reflexion at the inclined surface A C of the prism;) and, first, considering only the extreme red rays, if we drop a perpendicular from the eye on the base of the prism, and make this the axis of a cone, the side of which is inclined to the axis at the angle whose sine is $\frac{1}{\mu}$, (or the limiting angle for extreme red rays;) and if we conceive such rays to emanate in all directions *from the eye*, then all which fall *without* the circular base of this cone will be totally, but those within only partially reflected. Thus, were there no other than such red rays of this precise refrangibility, the region of partial reflexion would be a circle whose radius = height of the eye above the base × tangent of the angle whose sine is $\frac{1}{\mu} = \frac{\mathrm{H}}{\sqrt{\mu^2 - 1}}$. In like manner, the radius of the circular space, within which only a partial reflexion of violet rays takes place, is $\frac{\mathrm{H}}{\sqrt{\mu'^2 - 1}}$, or $\frac{\mathrm{H}}{\sqrt{(\mu + \delta\mu)^2 - 1}}$, being less than the value of the same radius for the red rays. Hence, in the space between the two circles, the violet rays will be totally, and the red only partially reflected; and, therefore, the whole of this space will have an excess of violet light. A similar reasoning holds good for the intermediate rays; and the shading away from the bright space without, to the comparatively dark one within, will, in consequence, be performed by the abstraction first of the red, next of the orange rays, and so on through the spectrum, leaving a residual light, which continually deviates more and more from white, and verges to blue. If now we suppose each ray to be incident in the contrary direction so as to be reflected to the eye instead of emanating from it, every thing will equally hold good, and the eye will see a bright space without; separated from an obscure space within the base of the cone, the transition from one to the other being not sudden, but marked by a blue border, the colour of which is more lively towards the interior. Now such is the fact, with one difference, however, that the coloured arch appears slightly tinged with pink on its convex side. This, as it is incompatible with theory, can be owing, it should seem, to no cause but contrast; a most powerful source of illusion in all the phenomena of colours, and of which this is, perhaps, one of the most striking and curious instances. Newton (*Optics*, part ii. exp. 16) takes no notice of this part of the phenomenon, (which was first observed and described by Sir W. Herschel,) though he gives the same explanation of the rest with that here set down. The effect of refraction at the side B A of the prism will somewhat modify the figure of the bow, giving it a tendency to a conchoidal form at great obliquities of the emergent rays.

556. Transmitted prismatic bow. If the side B C of the prism be covered with black paper, and a bright scattered light be thrown on the base from below, (as from an emeried glass applied with its rough side close to the base,) the converse of the above described phenomena will be seen. A totally black space will be seen beyond F, and a bright one within it. The separation being marked by a bow of a vivid red colour, graduating through orange and pale yellow into white, the red being outwards. It is evident that this phenomenon is, in all its parts, complementary to that of the blue bow seen by reflexion, and therefore requires no more particular explanation. It should be noticed, however, that in this bow no appearance of blue or violet within its concavity is ever seen; so that the effect which we have above attributed to contrast in the reflected bow has nothing corresponding to it in the transmitted one.

557. Reflexion at surfaces artificially polished explained. The intensity and regularity of reflexion at the external surface of a medium, is found to depend not merely on the nature of the medium, but very essentially on the degree of smoothness and polish of its surface. But it may reasonably be asked, how any regular reflexion can take place on a surface polished by art, when we recollect that the process of polishing is, in fact, nothing more than grinding down large asperities into smaller ones by the use of hard gritty powders, which, whatever degree of mechanical comminution we may give them, are yet vast masses, in comparison with the ultimate molecules of matter, and their action can only be considered as an irregular tearing up by the roots of every projection which may occur in the surface. So that, in fact, a surface artificially polished must bear somewhat of the same kind of relation to the surface of a liquid, or a crystal, that a ploughed field does to the most delicately polished mirror, the work of human hands. Now to this question the Newtonian doctrine furnishes an answer quite satisfactory. Were the reflexion of light performed by actual impact of its molecules upon those of the reflecting medium, no regular ordinary reflexion could ever take place at all, as it would depend entirely on the shape of the molecules, or asperities of the surface, and the inclinations of their surfaces to the general surface of the medium at the point of incidence, what should be the direction ultimately taken by each particular ray. Now these must vary in every possible manner in uncrystallized bodies, so that in reflexion from the surfaces of *these* the light would be uniformly scattered in every direction. On the other hand, in crystallized media, each molecule presenting only a limited number of strictly plane surfaces, and the corresponding faces of all being mathematically parallel, reflexion would indeed be regular; but its direction would be regulated only by that of the incident ray and the position of certain fixed lines within the crystal; and would be quite independent of either the smoothness or the inclination of the polished surfaces of it, whether natural or artificial; add to which, that instead of the reflected pencil of rays being *single*, it would in most cases be multiple. All these consequences are so contrary to fact, that it is evident we must suppose the distance to which the forces producing reflexion extend much greater not only than the size of, or interval between individual molecules, but even greater than the minute inequalities or furrows in the artificially polished surfaces of media. Granting this, the difficulty vanishes; for the average action of many molecules, or many corrugations, will present an uniformity, while individually they may offer the greatest diversity. To illustrate this, we need only cast our eyes on fig. 125, where A B represents the rough surface of a medium, and A C the radius of one of the spheres of attraction, or repulsive activity of a single molecule A. Conceiving now the summits of all the elevations a, b, c, d to lie in a plane, let spheres be described with their centres equal to A C. Then their intersections will generate a kind of mamillated surface $\alpha\,\beta\,\gamma\,\delta$, which, however, if the radii of the spheres be at all considerable with respect to the distances of their centres, will approach exceedingly near to a mathematical plane, infinitely more so than the surface A B need be supposed. Hence, a ray of light impinging on the medium will come within the sphere of its action not at an irregular surface, but nearly at a plane one; and the resultant action of all the molecules in action, supposing them distributed with uniformity over A B, will be perpendicular to this surface. The same will hold good of the layer of molecules (however interrupted) immediately under the summits b, c, d, &c., and of all the other

Light not reflected by direct impact on bodies.

But by forces at a distance.

layers into which the whole surface can be divided. So that the essential conditions on which the Newtonian doctrine of reflexion and refraction reposes, (viz. equality of force at equal distances from the general level of the surface, and the perpendicularity of its direction to that level,) still obtain.

558. Oblique regular reflexion from rough surfaces.

It is evident that the inequalities in the mamillary surfaces above described will become more considerable as their radii are diminished, or as the interval of their centres is greater, and in proportion will the regularity of reflexion and refraction be interrupted. Hence too it follows, that the more oblique the incidence of the ray, the greater may be the roughness of the surface which will give a regular reflexion; and this is perfectly consonant to fact, as may be easily tried with a piece of emeried glass, which, although so rough as to give no regular image at a perpendicular incidence, will yet give a pretty distinct one at great obliquities. The reasons are, first, that a very oblique ray will not require to penetrate so far within the sphere of repulsion, to have its motion perpendicular to the surface destroyed; and, secondly, that it cannot pass between two contiguous elevations or depressions of the imaginary surface $\alpha \beta \gamma \delta$, but by reason of its obliquity must traverse several of them, and thus undergo a more regular *average* exertion of the forces of the medium.

559. Regular refraction at surfaces artificially polished.

Thus the reflexion of light is explained on the Newtonian doctrine. But it may still be asked, how refraction at a surface artificially polished can ever be regular. In reflexion, the ray never reaches the asperities of the surface; it undergoes their average action, equalized by distance, and mutually compensated. In refraction, it is otherwise. Here the rays must actually traverse the surface, and must therefore actually pass through all its inequalities at every possible angle of obliquity. The answer to this is equally plain. Neither refraction nor reflexion are performed *close* to the surface, either wholly, or in great part. The greater part by far of the flexure of the ray is performed (either internally or externally) at a distance, out of the reach of these irregularities, and by the action of a much more considerable thickness of the medium than is occupied by them. Their action must be compared to the effect of mountains on the earth's surface in disturbing the general force of gravity. A stone let fall close to one of them, from a moderate height, follows not the true vertical but the direction of the deviated plumbline, which is sensibly different. Whereas, if let fall from the moon to the earth's centre, it would pass among them, were they greater a thousand fold than they are, without experiencing any sensible perturbation or change of direction in their neighbourhood.

560. In fact, however, no regular refraction can be obtained from surfaces sensibly rough, at all comparable to the regularity of their reflexion. This may arise from the impossibility of a refracted ray penetrating the surface at a sufficient degree of obliquity. It is, however, a remarkable fact, that the *regular* internal reflexion from a roughened surface, even at extreme obliquities, is scarcely sensible, even in cases where the external reflexion at the same obliquities is perfectly regular and copious. This would seem to indicate, that the forces which operate the external reflexion of a ray exert their energy wholly without the medium.

561. Intensity of the forces producing refraction.

Whatever be the forces by which bodies reflect and refract light, one thing is certain, that they must be incomparably more energetic than the force of gravity. The attraction of the earth on a particle near its surface produces a deflexion of only about 16 feet in a second; and, therefore, in a molecule moving with the velocity of light, would cause a curvature, or change of direction, absolutely insensible in that time. In fact, we must consider, first, that the time during which the whole action of the medium takes place, is only that within which light traverses the diameter of the sphere of sensible action of its molecules at the surface. To allow so much as a thousandth of an inch for this space is beyond all probability, and this interval is traversed by light in the $\frac{1}{12,672,000,000,000}$ part of a second. Now, if we suppose the deviation produced by refraction to be 30°, (a case which frequently happens,) and to be produced by a uniform force acting during a whole second; since this is equivalent to a linear deflexion of 200,000 miles × sin 30°, or of 100,000 miles = 33,000,000 × 16 feet, such a force must exceed gravity on the earth's surface 33,000,000 times. But, in fact, the whole effect being produced not in one second, but in the small fraction of it above mentioned, the intensity of the force operating it (see MECHANICS) must be greater in the ratio of the square of one second to the square of that fraction; so that the least improbable supposition we can make gives a mean force equal to $4,969,126,272 \times 10^{24}$ times that of terrestrial gravity. But in addition to this estimate already so enormous, we have to consider that gravity on the earth's surface is the resultant attraction of its whole mass, whereas the force deflecting light is that of only those molecules immediately adjoining to it, and within the sphere of the deflecting forces. Now a sphere of $\frac{1}{1000}$ of an inch diameter, and of the mean density of the earth, would exert at its surface a *gravitating* force only $\frac{1}{1000} \times \frac{\text{1 inch}}{\text{diameter of the earth}}$ of ordinary gravity, so that the actual *intensity* of the force exerted by the molecules concerned cannot be less than $\frac{1000 \times \text{earth's diameter}}{\text{1 inch}}$ (= 46,352,000,000) times the above enormous number, or upwards of 2×10^{44} when compared with the ordinary intensity of the gravitating power of matter. Such are the energies concerned in the phenomena of light on the Newtonian doctrine. In the undulatory hypothesis, numbers not less immense will occur; nor is there any mode of conceiving the subject which does not call upon us to admit the exertion of mechanical forces which may well be termed infinite.

562. Dr. Wollaston has proposed the observation of the angle at which total reflexion first takes place at the common surface of two media, the index of refraction of one of which is known, as a means of determining that of the other; and, in the *Philosophical Transactions for* 1802, has described an ingenious apparatus which gives a measure of the index required almost by inspection. If we lay any object under the base of a prism

Objection from the phenomena of dispersion.

it in any other light than as a most formidable objection to the undulatory doctrine. It will be shown presently that the deviation of light by refraction is a consequence of the difference of its velocities within and without the refracting medium, and that when these velocities are given the amount of deviation is also given. Hence it would appear to follow unavoidably, that rays of all colours must be in all cases equally refracted; and that, therefore, there could exist no such phenomenon as dispersion. Dr. Young has attempted to gloss over this difficulty, by calling in to his assistance the vibrations of the ponderable matter of the refracting medium itself, as modifying the velocity of the ethereal undulations within it, and that differently according to their frequency, and thus producing a difference in the velocity of propagation of the different colours; but to us it appears with more ingenuity than success. We hold it better to state it at once in its broadest terms, and call on the reader to suspend his condemnation of the doctrine for what it *apparently* will not explain, till he has become acquainted with the immense variety and complication of the phenomena which it will. The fact is, that neither the corpuscular nor the undulatory, nor any other system which has yet been devised, will furnish that complete and satisfactory explanation of *all* the phenomena of light which is desirable. Certain admissions must be made at every step, as to modes of mechanical action, where we are in total ignorance of the acting forces; and we are called on, where reasoning fails us, occasionally for an exercise of faith. Still, if we regard hypotheses and theories as no other way valuable than as means of classifying and grouping together phenomena, and of referring facts to laws which, though possibly empirical, are yet, so far as they are so, correct representations of nature, and as such must be deducible from real primary laws, whenever they shall be discovered, we cannot but admit their importance. The undulatory system especially is necessarily liable to considerable obscurities; as the doctrine of the propagation of motion through elastic media is one of the most abstruse and difficult branches of mathematical inquiry, and we are therefore perpetually driven to indirect and analogical reasoning, from the utter hopelessness of overcoming the mere mathematical difficulties inherent in the subject when attacked directly.

566. Objection from the rectilinear propagation of light answered.

It is thus that we are encountered at the very outset of its application with another objection, which, in the eyes of Newton, appeared decisive against its admission, but which has since been, in a considerable degree, overcome. How is it that *shadows* exist. Sounds make their way freely round a corner,—why does not light do so? A vibration propagated from a centre in an elastic medium, and intercepted by an immovable obstacle having a small orifice, ought to spread itself, it is said, from this orifice beyond the screen as from a new centre, and fill the space beyond with undulations propagated from it in every direction. Thus, as in Acoustics, the orifice is heard as a new source of sound; so, in Optics, it ought to be seen in all directions as a new luminary. To this the answer is, first, that it is not demonstrable that a vibratory motion communicated to one particle of an elastic medium is propagated with equal *intensity* to every surrounding molecule in whatever direction situated with respect to the line of its motion, though it is with equal *rapidity*; and therefore that we have no reason to presume, *à priori*, but rather the contrary, that the motions of the vibrating particles at the orifice should be propagated laterally with *equal* intensity in all directions; secondly, that it is not true, in fact, that sounds are propagated round the corner of an obstacle *with the same intensity* as in their original direction, as any one may convince himself by the following simple experiment. Take a common tuning fork, and, holding it (when set in vibration) about three or four inches from the ear, with its flat side towards it, when its sound is distinctly heard, let a strip of card, somewhat longer than the flat of the tuning fork, be interposed, at about half an inch from the fork. The sound will be almost entirely intercepted by it; and if the card be alternately removed and replaced in pretty quick succession, alternations of sound and silence will be perceived; proving that the undulations of the air are by no means propagated with equal intensity by the circuitous route round the edge of the card, as by the direct one. Indeed any one has only, to be convinced of the fact, to attend to the sound of a carriage in the act of turning a corner from the street in which he happens to be tò an adjoining one; to which we may add, that, even when there is no obstacle in the way, sounds are by no means equally audible in all directions from the sounding body, as any one may convince himself by holding a vibrating tuning fork, or pitchpipe, near his ear, and turning it quickly on its axis. This last phenomenon was first noticed, we believe, by Dr. Young, (*Phil. Trans.*, 1802, p. 25,) and since more fully described (in *Schweiggers Jahrbuch*, 1826) by M. Weber. Now if there be any inequality *at all* in the intensity of the direct and lateral propagation of undulations in a medium, it must arise from the constitution of the medium, and the proportion of the amplitude of the excursions of the vibrating particles to their distance from each other; and may therefore easily be conceived to differ in any imaginable degree in different media, and there is, at least, no absurdity in supposing the ether so constituted as to admit of comparatively very feeble lateral propagation. Now, thirdly, in point of fact, light does spread itself in a certain small degree into the shadows of bodies, out of its strict rectilinear course, giving rise to the phenomena of *inflexion* or *diffraction*, of which more presently, and which are completely accountable for on the undulatory doctrine, and form, in fact, its strongest points. For further information on this confessedly abstruse subject, the reader must consult our article on SOUND, and the works cited at the end of this Essay. It is enough here to show, that the objection which has been urged by Newton and his followers with such force against the doctrine of undulations, is really not conclusive against it, but founded rather on inadequate conceptions of the nature of elastic fluids, and the laws of their undulations.

567. Mode in which the retina is excited by vibrations of ether.

Although any kind of impulse, or motions regulated by any law, may be transferred from molecule to molecule in an elastic medium, yet in the theory of light it is supposed that only such primary impulses as recur according to regular periodical laws, at equal intervals of time, and repeated many times in succession, can affect our organs with the sensation of light. To put in motion the molecules of the nerves of our retina with sufficient efficacy, it is necessary that the almost infinitely minute impulse of the adjacent ethereal molecules should be often and regularly repeated, so as to multiply, and, as it were, concentrate their effect. Thus, as a great pendulum may be set in swing by a very minute force often applied at intervals exactly equal to its time

570. *Corol.* Hence the excursions of the molecule to and fro will consist of four principal phases, in each of which its motion is similar, but in contrary directions, or on contrary sides of the centre. In the first phase the molecule is to the *right* of the centre of motion, and is approaching the centre, or moving from *right* to *left*. In the second, it is to the left of the middle point, and moving from it, or still *from right* to *left*. These two phases we shall term the *positive phases*. In the third phase the molecule lies on the left side, and its motion is towards the centre, and from left to right. In the fourth, it is to the right again, receding from the centre, and moving still from left to right. These we shall term the *negative phases* of its vibration.

571. Laws of rectilinear vibrations of an ethereal molecule.

Proposition. To define the rectilinear vibrations of any molecule of the ether, propagated from a luminous particle vibrating as in the last proposition.

In the propagation of motions through elastic, uniform media, the same or a similar motion to that of any one molecule is communicated to every other in succession; but this communication occupies time, and the motion of a molecule at a distance from the origin of the vibrations does not commence till after the lapse of an interval of time proportional to that distance, being the time in which the propagated impulse, whether of sound or light, &c. runs over that distance with a certain uniform velocity due to the intrinsic elasticity of the medium, and which in the case of light is about 200,000 miles per second; in that of sound about 1100 feet. And when the vibration of the original source of motion has ceased, that of the ethereal molecule does not cease on the instant, but continues for a time equal to that which elapsed before its commencement. Hence, if we call V the velocity of light, and D the distance of the molecule from the luminous point, $\frac{D}{V}$ will be the interval between the commencement of the motion of the latter and of the former; hence $-$ t being the time elapsed at any instant since the commencement of the first positive phase of the vibration of the luminous point, $t - \frac{D}{V}$ will be the corresponding time in the case of the ethereal molecule. Thus we have, for the equations of the motions of the former,

$$x = a \,.\, \cos 2\pi \,.\, \frac{t}{T}; \qquad v = b \,.\, \sin 2\pi \, \frac{t}{T}; \text{ where } b = a \sqrt{E}$$

and in that of the latter

$$x = a \,.\, \cos 2\pi \,.\, \left(\frac{t - \frac{D}{V}}{T}\right); \qquad v = \beta \,.\, \sin 2\pi \left(\frac{t - \frac{D}{V}}{T}\right); \text{ where } \beta = a \sqrt{E}$$

a being the semiamplitude of the vibration, or the extent of the excursion of the ethereal molecule from its point of rest.

572. *Corol.* Hence it is evident that the actual velocity of the molecules of ether may be less in any proportion than that of light; for the maximum value of v depends for its numerical magnitude solely on a, or on the amplitude of excursion, and on E, and not at all on V the velocity of propagation of the wave.

573. Waves of light defined.

Corol. 2. If we suppose the luminous molecule to have made, from the commencement of its motion, any number of vibrations and parts of a vibration in the time t; then if we consider an ethereal molecule at a distance V . t from it in any direction, (i. e. situated in a spherical surface whose radius is V . t,) this molecule will be just beginning to be put in motion. If we suppose another spherical surface concentric with the former, but having its radius less than the former by V . T, which in future we shall call λ, every particle situated in this surface will have just completed one vibration, and be commencing its second, and so on. The interval between these surfaces will comprehend, arranged in spherical, concentric shells, molecules in every phase of their vibrations,—those in each shell being in the same phase. This assemblage of molecules is termed *a wave*, and as the impulse continues to be propagated forwards it is evident that the wave will continue to increase in radius, and will comprehend in succession all the molecules of the medium to infinity.

574. Undulations or pulses.

Definition. The interval between the internal and external surface of a luminous wave is called an *undulation*, or a pulse, and its length is evidently $= V \,.\, T = \lambda$, or the space run over by light in the time T of one complete period, or vibration of the luminous molecule. It is therefore proportional to that time.

575. Different colours have different lengths of their undulations.

Hence the lengths of the undulations of differently coloured rays differ *inter se*. For, by Postulate 6, the number of vibrations made in any given time by the ethereal particles determines the colour. Now the more numerous the vibrations are, *dato tempore*, the shorter their duration; hence T, which represents this duration, is *less*; and therefore λ, or the length of the undulation less for the violet than for the red rays. From experiments to be presently described, it has been found, that the lengths of the undulations in air, or the values of λ for the different rays, as also the number of times they are repeated in one second, are as in the following table :

a greater at rest, it will be reflected, and with a momentum which is greater in proportion to the difference in size of the balls.

581. Principles. But to render an account of oblique reflexion and refraction, and the other phenomena we shall have to speak of, it will be necessary to lay down the following principles, which are either self-evident or follow immediately from the elementary principles of dynamics.

582. Superposition of small motions. 1. When any number of very minute impulses is communicated at once to the particles of any medium, or of any mechanical system under the influence of any forces, the motion of each particle at any instant will be the sum of all the motions which it would have at that instant, had each of the impulses been communicated to the system alone, (the word sum being understood in its algebraical sense.)

583. Principle of secondary waves. 2. Every vibrating molecule in an elastic medium, whether vibrating by an original impulse, or in consequence of an impulse propagated to it from others, may be regarded as a centre of vibration from which a system of secondary waves emanates in all directions, according to the laws of the propagation of waves in the medium.

Proposition. In the reflexion of light on the undulatory doctrine, the angle of incidence is equal to that of reflexion.

584. Law of reflexion at a plane. Let A B be a plane surface separating the two media, and S the luminous point propagating a series of spherical waves, of which let A *a* be one. So soon as this reaches the surface at A, a partial reflexion will take place; and regarding the point A as a new centre of vibration, spherical waves will begin to be propagated from it as a centre, one of which proceeds forwards *into* the reflecting medium, with a velocity greater or less than that of the incident wave, as the case may be; the other backwards into the medium of incidence, with a velocity equal to that of the incident wave. It is only with the latter we are at present concerned. Conceive now the wave A *a* to move forward into the position B *b*; then in the time that it has run over the space P B, the wave propagated from A will have run back over a distance $A\,d = P\,B$, and the hemisphere whose radius is A *d* will represent this wave. Between A and B take any point X, and describe the hemispheric surface X *c*. Then regarding X as a centre of vibration, its vibrations will not commence till the wave has reached it. It will, therefore, begin to vibrate later than A, by the whole time the wave A *a* takes to run over P Q; but when once set in vibration, it propagates backwards a spherical wave with the same velocity, so that when the original wave has advanced into the situation B *b*, the wave from X will have expanded into a hemisphere, whose radius X *c* is equal to P B, P Q, or A B. Now this being true of every point X, if we conceive a surface touching all these hemispheres in *d*, *c*, B, this surface will mark the points at which the reflected impulse has just arrived, and which just begins to move when the original wave has reached B, and will, therefore, be the surface of the reflected wave. Conceive now the spherical surface *b* B prolonged below the plane A B, as represented by the dotted line D C B, and the same of the spheres about A and X. Then the spherical surfaces D C B and C *c* being both perpendicular to S X C, must touch each other in C, hence the surface touching all the hemispheres about A, X, &c. as centres, *below* A B is a segment of a sphere having S for a centre, and therefore the surface B *c d* or the reflected wave is a segment of a sphere having its centre at *s* as much below the line A B as S is above it.

Now to an eye placed at X, the luminous point S will appear in the direction S X perpendicular to the incident wave, and the eye placed in *c* will perceive the reflected image of S at *s* in the direction *c s*, perpendicular to the reflected wave; but *c s* passes through X, because the spheres *c* C and B *b* touch at *c*. Therefore the *ray* by which *s* is seen at *c* passes through X. But the surfaces B D, B *d* being similar and equal, the angle $B\,X\,c = B\,X\,C = A\,X\,S$, that is, the angle of incidence is equal to that of reflexion. Q. E. D.

585. Reflexion at curved surfaces. Fig. 128. *Cor.* If the reflecting surface be not a plane, the reflected wave will not be spherical; its form is, however, easily determined as follows: Suppose the direct wave to have assumed the position B *b*. Take any point X in the reflecting surface, and describe the sphere X Q, and with the centre X and radius $= B\,Q$, describe another sphere. Do this for every point in the surface A B, and the surface which is a common tangent (as B *c d*) to all these spheres, is the surface of the reflected wave, because it marks the farthest limit to which the reflected impulse has reached in all directions at the instant when the direct impulse has reached B. Now take Y infinitely near to X, and, making the same construction at Y, let *c*, *e* be the points in the reflected wave to which X *c* and Y *e* are respectively perpendicular. Draw X *r* perpendicular to Y *e*, and X *q* to S Y *q*, then, since $Y\,e = S\,B - S\,Y$, and $X\,c = S\,B - S\,X$, we have $Y\,e - X\,c$, or $Y\,r = S\,X - S\,Y = Y\,q$, and X Y being common to the right angled triangles X Y *r*, X Y *q*, the angle *r* Y X must be equal to X Y *q* or to S Y A, so that the same law of reflexion holds good in curve as in plane surfaces.

586. Law of refraction. Fig. 129. *Proposition.* To demonstrate the law of refraction in the undulatory system.

Let S, fig. 129, be a luminous point, and let any wave propagated from it reach in succession the points Y, X, B of any curve surface Y X B of a refracting medium, whereof X and Y are supposed infinitely near each other. As the wave strikes Y, X, B, each of these points will become centres of undulation, which will be propagated in the refracting medium with a velocity different from that of light in the medium of incidence, by reason of their different elasticities, (Postulate 3.) Let $V : v ::$ velocity in the first medium to that in the second, (a constant ratio by hypothesis,) and, describing the sphere B Q R, take $X\,c = \frac{v}{V} \cdot Q\,X$ and $Y\,e = \frac{v}{V} \cdot Y\,R$, then will X *c* and Y *e* represent the spaces run over by the refracted secondary waves propagated from X and Y respectively, when the direct wave has reached B. Hence, if about X and Y as centres, and with these radii we describe spheres, and suppose *e*, *c* to be points in the curve surface which is a tangent to all such spheres, it is clear that X *c* and Y *e* will be perpendicular to this surface, that is, to the surface of the refracted primary wave; hence, X *c* and Y *e* will be the directions of the refracted rays at X and Y. Draw X *q*, X *r* perpendicular

594. Applied to determine refractive indices. If photometrical experiments enable us to determine the proportion of the reflected to the incident light, we may thence conclude the index of refraction of the reflecting medium, and that in cases where no other mode will apply. Thus, M. Arago having ascertained that about half the incident light is reflected at a perpendicular incidence from mercury, we have in this case $\left(\frac{\mu' - \mu}{\mu' + \mu}\right)^2 = \frac{1}{2}$; $\frac{\mu'}{\mu} = 5{\cdot}829$ for the refractive index of mercury out of air; and this is perfectly consonant to the general tenor of optico-chemical facts, which assign to the heavy and especially to the white metals (as indicated in their transparent combinations) enormous refractive and dispersive powers. This curious and interesting application has not been overlooked by Dr. Young in the Paper alluded to.

595. To complete the theory of reflexion and refraction on the undulatory hypothesis, it will be necessary to show what becomes of those oblique portions of the secondary waves, diverging in all directions from every point of the reflecting or refracting surfaces (as X γ, fig. 127) which do not conspire to form the principal wave. But to understand this, we must enter on the doctrine of the interference of the rays of light,—a doctrine we owe almost entirely to the ingenuity of Dr. Young, though some of its features may be pretty distinctly traced in the writings of Hooke, (the most ingenious man, perhaps, of *his* age,) and though Newton himself occasionally indulged in speculations bearing a certain relation to it. But the unpursued speculations of Newton, and the *appercus* of Hooke, however distinct, must not be put in competition, and, indeed, ought scarcely to be mentioned with the elegant, simple, and comprehensive theory of Young,—a theory which, if not founded in nature, is certainly one of the happiest fictions that the genius of man has yet invented to group together natural phenomena, as well as the most fortunate in the support it has unexpectedly received from whole classes of new phenomena, which at their first discovery seemed in irreconcileable opposition to it. It is, in fact, in all its applications and details one succession of *felicities*, insomuch that we may almost be induced to say, if it be not true, it deserves to be so. The limits of this Essay, we fear, will hardly allow us to do it justice.

§ III. *Of the Interference of the Rays of Light.*

596. General principles of interference. The principle on which this part of the theory of Light depends, is a consequence of that of the "Superposition of small motions" laid down in Art. 583. If two waves arrive at once at the same molecule of the ether, that molecule will receive at once both the motions it would have had in virtue of each separately, and its resultant motion will, therefore, be the diagonal of a parallelogram whose sides are the separate ones. If, therefore, the two component motions agree in direction or very nearly so, the resultant will be very nearly equal to their sum, and in the same direction. If they very nearly oppose each other, then to their difference. Suppose, now, two vibratory motions consisting of a series of successive undulations in an elastic medium, all similar and equal to each other, and indefinitely repeated, to arrive at the same point from the same original centre of vibration, but by different routes (owing to the interposition of obstacles or other causes) exactly, or very nearly in the same final direction; and suppose, also, that owing either to a difference in the lengths of the routes, or to a difference in the velocities with which they are traversed, the time occupied by a wave in arriving by the first route (A) is less than that of its arriving by the other (B). It is clear, then, that any ethereal molecule placed in any point common to the two routes A, B, will begin to vibrate in virtue of the undulations propagated along A before the moment when the first wave propagated along B reached it. Up, then, to this moment its motions will be the same as if the waves along B had no existence. But after this moment, its motions will be very nearly the sum or difference of the motions it would have separately in virtue of the two undulations each subsisting alone, and the more nearly, the more nearly the two routes of arrival agree in their final direction.

597. Case of complete discordance. Now it may happen, that the difference of the lengths of the routes or the difference of velocities is such, that the waves propagated along B shall reach the intersection exactly one-half an undulation behind the others, *i. e.* later by exactly half the time of a wave running over a space equal to a complete undulation. In that case, the molecule which in virtue of the vibrations propagated along A would (at any future instant) be in one phase of its excursions from its point of rest, would, in virtue of those propagated along B, if subsisting alone, be at the same instant in exactly the opposite phase, *i. e.* moving with equal velocity in the contrary direction. (See Art. 570.) Hence, when both systems of vibration coexist the motions will constantly destroy each other, and the molecule will remain at rest. The same will hold good if the difference of routes or velocities be such, that the vibrations propagated along B shall reach the intersection of the routes exactly $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$, &c. of a complete period of undulation after those propagated along A; for the similar phases of vibration recurring periodically, and being (by hypothesis) continually repeated for an indefinite time, it is no matter whether the first vibration propagated along B be superimposed on, *or interfere with* (as it is called) the first, or any subsequent one propagated along A, provided the difference of their phases be the same.

598. Case of complete accordance. On the other hand it may happen, that the waves propagated along B do not reach the intersection till exactly one, two, or more whole periods after the corresponding waves propagated along A. In this case, the molecule at the intersection will, at any instant subsequent to the time of arrival of the first wave along B, be agitated at once by both vibrations in the *same* phase, and therefore the velocity and amplitude of its excursions will, instead of being destroyed, be doubled.

of any assumed molecule (M) at the instant t. Let V represent the velocity of light, and λ the length of an undulation, and δ the distance run over by light in the time t. Then will $\delta = \mathrm{V}\,t$ and $\lambda = \mathrm{V\,T}$, and consequently $\frac{t}{\mathrm{T}} = \frac{\delta}{\lambda}$. Suppose v_0 to represent the velocity of a vibrating molecule at the origin of the ray at the instant t, then will $v_0 = a\,.\,\sin\left(2\,\pi\,.\,\frac{t}{\mathrm{T}}\right) = a\,.\,\sin\left(2\,\pi\,\frac{\delta}{\lambda}\right)$. But the molecule M moves only by an impulse communicated to it from the origin, and therefore all its motions are later than those at the origin by a constant interval equal to the time required for light to run over the distance of M from the origin. Call D that distance, then $\frac{\mathrm{D}}{\mathrm{V}}$ is the interval in question, and $t - \frac{\mathrm{D}}{\mathrm{V}}$ is the time elapsed at the instant t, since the molecule commenced its periodic motions; therefore its velocity v must $= a\,.\,\sin\left(2\,\pi\,\frac{t - \frac{\mathrm{D}}{\mathrm{V}}}{\mathrm{T}}\right)$, and consequently $\mathrm{C} = -\frac{\mathrm{D}}{\mathrm{V}}$, or $\mathrm{D} = -\,\mathrm{V\,C}$.

Hence we see that the distance of the molecule M from the origin of the ray, is equal to the space described by Light, in a time represented by the arbitrary constant C, and is therefore given when C is so, and *vice versâ*.

610. *Corol.* Since $\mathrm{V\,T} = \lambda$ the expression for the velocity becomes

$$v = a\,.\,\sin 2\,\pi\,.\left(\frac{t}{\mathrm{T}} - \frac{\mathrm{D}}{\lambda}\right) = a\,.\,\sin 2\,\pi\left(\frac{\delta - \mathrm{D}}{\lambda}\right) \text{ and similarly } x = a\,.\,\cos 2\,\pi\left(\frac{\delta - \mathrm{D}}{\lambda}\right)$$

611. *Proposition.* To determine the colour, origin, and intensity of a ray resulting from the interference of two similar rays, differing in origin and intensity.

Resultant of two interfering rays investigated

Let a^2 and a'^2 be the intensities of the rays, or a, a' their amplitudes of vibration, and take $a = a\,.\,\sqrt{\mathrm{E}}$, $a' = a'\,.\,\sqrt{\mathrm{E}}$, then, if we put θ for the phase of vibration of a molecule M at the instant t which it would be in, in virtue of the first system of waves (A), and $\theta + k$ for its phase, in virtue of the other (B), $\frac{k}{2\,\pi}\,.\,\mathrm{T}$ will represent the time taken by light to run over a space equal to the interval of their origin, and the velocities and distances from rest which M would have, separately at the instant t, in virtue of the two rays, will be

$$v = a\,.\,\sin\theta\;;\; v' = a'\,.\,\sin(\theta + k), \text{ and } x = a\,.\,\cos\theta\,;\; x' = a'\,.\,\cos(\theta + k).$$

Therefore, in virtue of the resulting ray, it will have the velocity

$$v + v' = a\,.\,\sin\theta + a'\,.\,\sin(\theta + k), \text{ and } x + x' = a\,.\,\cos\theta + a'\,.\,\cos(\theta + k).$$

Let the former be put equal to $\mathrm{A}\,.\,\sin(\theta + \mathrm{B})$, the possibility of which assumption will be shown by our being able to determine A and B, so as to satisfy this condition. Then we have

$$(a + a'\,.\,\cos k)\sin\theta + a'\,.\,\sin k\,.\,\cos\theta = \mathrm{A}\,.\,\cos\mathrm{B}\,.\,\sin\theta + \mathrm{A}\,.\,\sin\mathrm{B}\,.\,\cos\theta,$$

and equating like terms,

$$\mathrm{A}\,.\,\cos\mathrm{B} = a + a\,.\,\cos k\,;\; \mathrm{A}\,.\,\sin\mathrm{B} = a'\,.\,\sin k,$$

whence we get, dividing one by the other,

$$\tan\mathrm{B} = \frac{a'\,.\,\sin k}{a + a'\,.\,\cos k}\,;\; \mathrm{A} = \frac{a'\,.\,\sin k}{\sin\mathrm{B}} = \sqrt{a^2 - 2\,a\,a'\,.\,\cos k + a'^2}$$

and these values being determined, A and B are known, and, therefore, $v + v' = \mathrm{A}\,.\,\sin(\theta + \mathrm{B})$. Similarly, if we put $x + x' = \mathrm{A}'\,.\,\cos(\theta + \mathrm{B}')$ we obtain values of A′ and B′ precisely similar, writing only $a\,a'$ for a, a' respectively.

612. *Corol.* 1. Hence we conclude, 1st. that the resultant ray is similar to the component ones, and has the same period, i. e. the same colour.

613. *Corol.* 2. M. Fresnel has given the following elegant rule for determining the amplitude and origin of the resultant ray, which follows immediately from the value of A and the equation $\sin\mathrm{B} = \frac{a'}{\mathrm{A}}\,.\,\sin\mathrm{K}$ above found.

Fresnel's theorem.

Construct a parallelogram, having its adjacent sides proportional to the amplitudes a, a' of the component rays, and the angle between them measured by a circular arc to radius unity, equal to the differences of their phases, then will the diagonal of this parallelogram represent on the same scale the amplitude of the resulting ray, and the angle included between it, and either side will represent the difference of phases between it and the ray corresponding; or, which comes to the same thing, the difference of their origins (when reduced to space.)

619. Suppose now two systems of waves, or two rays coincident in direction, to interfere with each other. If we accent the letters of the above expressions to represent corresponding quantities for the second system, we shall have

$$\left.\begin{aligned} X = x + x' &= a \,.\, \cos(\theta + p) + a' \,.\, \cos(\theta + p') \\ Y = y + y' &= b \,.\, \cos(\theta + q) + b' \,.\, \cos(\theta + q') \\ Z = z + z' &= c \,.\, \cos(\theta + r) + c' \,.\, \cos(\theta + r') \end{aligned}\right\} \quad (6)$$

and similarly for the velocities $u + u'$, $v + v'$, $w + w'$. In the same manner, then, as we proceeded in the case of two similar rays, let us suppose

$$a \,.\, \cos(\theta + p) + a' \,.\, \cos(\theta + p') = A \,.\, \cos(\theta + P)$$

and developing

$$(a \,.\, \cos p + a' \,.\, \cos p') \cos\theta - (a \,.\, \sin p + a' \,.\, \sin p') \sin\theta = A \,.\, \cos P \,.\, \cos\theta - A \,.\, \sin P \,.\, \sin\theta,$$

whence we get

$$\left.\begin{aligned} &\tan P = \frac{a \,.\, \sin p + a' \,.\, \sin p'}{a \,.\, \cos p + a' \,.\, \cos p'}\,; \quad A = \frac{a \,.\, \sin p + a' \,.\, \sin p'}{\sin P} \\ \text{or,} \quad &A = \sqrt{a^2 + 2\,a\,a' \,.\, \cos(p - p') + a'^2} \end{aligned}\right\}; \quad (7)$$

Thus we have $X = A \,.\, \cos(\theta + P)$, and, similarly, $Y = B \,.\, \cos(\theta + Q)$, and $Z = C \,.\, \cos(\theta + R)$, and a process exactly similar gives us the corresponding expressions for the velocities.

Composition and resolution of vibrations generally.

620. Thus we see that the same rules of composition and resolution apply to dissimilar as to similar vibrations. Each vibration must first be resolved into three rectilinear vibrations in three fixed planes at right angles to each other. These must be separately compounded to produce new rectilinear vibrations in the coordinate planes, which together represent the resulting elliptic vibration, and will have the same period as the component ones. By inverting the process, a vibration of this kind may be resolved into any number of others we please, having the same period.

Case of interference of rectilinear vibrations.

621. A great variety of particular cases present themselves, of which we shall examine some of the principal. And first, *when the interfering vibrations are both rectilinear.*

Since the choice of our coordinate planes is arbitrary, let us suppose that of the x, y to be that in which both the vibrations are performed. Of course the resulting one will be performed in the same. Therefore we may put $z = 0$, or $c = 0$, $c' = 0$, and content ourselves with making

$$\left.\begin{aligned} x = a \,.\, \cos(\theta + p)\,; \quad y = b \,.\, \cos(\theta + p) \\ x' = a' \,.\, \cos(\theta + p')\,; \quad y' = b' \,.\, \cos(\theta + p') \end{aligned}\right\}; \quad (8)$$

The resultant vibration is the general elliptic.

because $\dfrac{x}{y}$ and $\dfrac{x'}{y'}$ are constant in this case, and X, Y, A, B, P, Q, denoting as in the general case, we have

$$X = A \,.\, \cos(\theta + P)\,; \quad Y = B \,.\, \cos(\theta + Q)\,;$$

and, by elimination of θ,

$$\left(\frac{X}{A}\right)^2 + \left(\frac{Y}{B}\right)^2 - 2\cos(P - Q) \,.\, \frac{X\,Y}{A\,B} = \sin(P \quad Q)^2; \quad (9)$$

where A, B, P, Q, are determined as in equations, (7.) In the general case, then, the resulting vibration is elliptic.

Case when the resultant is rectilinear.

622. The ellipse degenerates into a straight line by the diminution of its minor axis when $P = Q$. Now this gives $\tan P = \tan Q$, or

$$\frac{a \,.\, \sin p + a' \,.\, \sin p'}{a \,.\, \cos p + a' \,.\, \cos p'} = \frac{b \,.\, \sin p + b' \,.\, \sin p'}{b \,.\, \cos p + b' \,.\, \cos p'}$$

which, reduced, takes the form

$$\left(\frac{a'}{a} - \frac{b'}{b}\right) \,.\, \sin(p - p') = 0.$$

Case when their directions coincide.

There are, therefore, two cases, and two only in which the resulting vibration is rectilinear. The first, when $p - p' = 0$, or when the component vibrations have a common origin, or are in complete accordance; the other, when $\dfrac{a'}{a} = \dfrac{b'}{b}$, that is, when they are both performed in one plane, and in the same direction. For if we call m and m' the amplitudes, and ψ, ψ' the angles they make with the axis of the x, we have

$$a = m \,.\, \cos\psi\,; \quad b = m \,.\, \sin\psi\,; \quad a' = m' \,.\, \cos\psi'\,; \quad b' = m' \,.\, \sin\psi',$$

so that the above equation is equivalent to $\tan\psi = \tan\psi'$, or $\psi = \psi'$.

628. The latter case we have already fully considered. In the former, we have $\cos(p - p') = 0$, and, therefore,

$$A = a + a'\,; \quad B = b + b'\,; \quad P = p\,; \quad Q = p,$$

these elements, and in each of which the corresponding values of f are exactly half an undulation ($\frac{1}{2}\lambda$) greater than in the preceding, so that (for instance) $BX = AX + \frac{1}{2}\lambda$, $CX = BX + \frac{1}{2}\lambda$, &c. Then it is evident, that the vibrations which reach X simultaneously from the corresponding portions of any two consecutive ones, as of A B and B C, will be in exactly opposite phases; and, therefore, were they of equal intensity, and in precisely the same direction, would interfere with, and destroy each other. Now, first, with regard to their intensity, this depends on the magnitudes of the elements of the wave A B, from which they are derived, and on the law of lateral propagation. Of the latter, we know little, *à priori;* but all the phenomena of light indicate a very rapid diminution of intensity, as the direction in which the secondary undulations are propagated deviates from that of the primary. With respect to the former, it is evident that the elements in the immediate vicinity of the perpendicular A X, corresponding to a given increment df of the distance from X, are much larger than those remote from it; so that all the elements of the portion A B are much larger than those in B C, and these again than in those of C D, and so on. Thus the motion transmitted to X from any element in A B will be much greater than that from the corresponding one in B C, and that again greater than that from the element in C D, and so on. Thus the motion arriving at G, from the whole series of corresponding elements, will be represented by a series such as $A - B + C - D + E - F +$ &c., in which each term is successively greater than that which follows. Now it is evident that the terms approach with great rapidity to equality; for if we consider any two corresponding elements as M, N at a distance from A at all considerable, the angles X M and X N make with the surface approach exceedingly near to equality, so that the obliquity of the secondary wave to the primary, and of course its intensity, compared with that of the direct wave, is very nearly alike in both; and the elements M, N themselves, at a distance from the perpendicular, approach rapidly to equality, for the elementary triangles M m o, M n p are in this case very nearly similar, and have their sides $m\,o$, $n\,p$ equal by hypothesis. Finally, the lines M X, N X approach nearer to each other in direction so as to produce a more complete interference, as their distance from A is greater.

629. Thus we see that the terms of the series $A - B + C - D +$ &c., at a distance from its commencement, have on all accounts (viz. their smallness, near approach to equality, and disposition to interfere) an extremely small influence on its value; and as the same is true of every set of corresponding elements into which the portions A B, B C, &c. are divided, it is so of their joint effect, so that the motion of the molecule X is governed entirely by that of the portion of the wave A B C immediately contiguous to A, the secondary vibrations propagated from parts at a distance mutually interfering and destroying each others effect.

630. It is obvious, that in the case of refraction or reflexion, we may substitute for the wave A M the refracting or reflecting surface; and for the perpendicular X A the primary refracted ray, when the same things, *mutatis mutandis,* will hold good. See M. Fresnel's Paper entitled *Explication de la Réfraction dans le Système des Ondes,* published in the *Bulletin de la Société Philomatique,* October, 1821.

631. Case of a wave transmitted through a limited aperture.

This is the case when the portion of the wave A B C D whose vibrations are propagated to X is unlimited, or at least so considerable, that the last term in the series $A - B + C -$ &c. is very minute compared with the first. But if this be not the case, as, if the whole of a wave except a small part about A be intercepted by an obstacle, the case will be very different. It is easy on this supposition to express by an integral the intensity of the undulatory motion of X, compared with what it would be on the supposition of no obstacle existing. For this purpose, let $d^2 s$ be the magnitude of any vibrating element of the surface, f its distance from $X = MX$, and let $\phi(\theta)$ be the function of the angle made by a laterally-divergent vibration with the direct one, which expresses its relative intensity, and which is unity when $\theta = 0$, and diminishes with great rapidity as θ increases. Then if t be the time since a given epoch, $\lambda =$ the length of an undulation, $SA = a$, the phase of a vibration arriving at X by the route S M X will be $2\pi\left(\frac{t}{T} - \frac{a+f}{\lambda}\right)$, and the velocity produced in X thereby will be represented by $\alpha \,.\, d^2 s \,.\, \phi(\theta) \,.\, \sin 2\pi\left(\frac{t}{T} - \frac{a+f}{\lambda}\right)$, so that the whole motion produced will be represented by

$$\int\!\!\int \alpha \,.\, d^2 s \,.\, \phi(\theta) \,.\, \sin 2\pi \left\{\frac{t}{T} - \frac{a+f}{\lambda}\right\}$$

the integral being extended to the limits of the aperture.

632. *Corol.* 1. If but a very small portion of the wave be permitted to pass, as in the case of a ray transmitted through a very small hole, and received on a distant screen, θ and $\phi(\theta)$ are very nearly constant, so that the motion excited in X is in this case represented by

$$\alpha \,.\, \phi(\theta) \int\!\!\int d^2 s \,.\, \sin 2\pi \left\{\frac{t}{T} - \frac{a+f}{\lambda}\right\}.$$

We shall have occasion to revert to these expressions hereafter.

§ IV. *Of the Colours of Thin Plates.*

633. General account of the phenomena.

Every one is familiar with the brilliant colours which appear on soap-bubbles; with the iridescent hues produced by heat on polished steel or copper; with those fringes of beautiful and splendid colours which appear in the cracks of broken glass, or between the laminæ of fissile minerals, as Iceland spar, mica, sulphate of lime, &c. In all these, and an infinite variety of cases of the same kind, if the fringes of colour be examined with care they will be found to consist of a regular succession of hues, disposed in the same order, and determined, obviously, not by any colour in the medium itself in which they are formed, or on whose surfaces they appear, but solely by its greater or less thickness. Thus a soap-bubble (defended from currents of air by being placed under a glass) at first appears uniformly white when exposed to the dispersed light of the sky at an open window; but, as it grows thinner and thinner by the subsidence of its particles, colours begin to appear at its top where thinnest, which grow more and more vivid, and (if kept perfectly still) arrange themselves in beautiful horizontal zones about the highest point as a centre. This point, when reduced to extreme tenuity, becomes *black*, or loses its power of reflecting light almost entirely. After which the bubble speedily bursts, its cohesion at the vertex being no longer sufficient to counteract the lateral attraction of its parts.

634. Rings formed between convex glasses.

But as it is a matter of great delicacy to make regular observations on a thing so fluctuating and unmanageable as a soap-bubble, the following method of observing and studying the phenomena is far preferable. Let a convex lens, of a very long focus and a good polish, be laid down on a plane glass, or on a concave glass lens having a curvature somewhat less than the convex surface resting on it; so that the two shall touch in but a single point, and so that the interval separating the surfaces in the surrounding parts shall be exceedingly small. If the surfaces be very carefully cleaned from dust before placing them together, and the combination be laid down before an open window in full daylight, the point of contact will be seen as a black spot in the general reflexion of the sky on the surfaces, surrounded with rings of vivid colours. A glass of 10 or 12 feet focus laid on a plane glass, will show them very well. If one of shorter focus be used, the eye may be assisted by a magnifying glass. The following phenomena are now to be attended to:

635. Order of succession of the colours.

Phenomenon 1. The colours, whatever glasses be used, provided the incident light be white, always succeed each other in the very same order; that is, beginning with the central black spot, as follows:

First ring, or first order of colours,—*black, very faint blue, brilliant white, yellow, orange, red.*

Second ring, or second order,—*dark purple or rather violet, blue, green,* (very imperfect, a yellow-green,) *vivid yellow, crimson red.*

Third ring, or third order,—*purple, blue, rich grass green, fine yellow, pink, crimson.*

Fourth ring, or fourth order,—*green,* (dull and bluish,) *pale yellowish pink, red.*

Fifth ring, or fifth order,—*pale bluish green, white, pink.*

Sixth ring, or sixth order,—*pale blue-green, pale pink.*

Seventh ring, or seventh order,—*very pale bluish green, very pale pink.* After these, the colours become so faint that they can scarcely be distinguished from white.

636. On these we may remark, that the green of the third order is the only one which is a pure and full colour, that of the second being hardly perceptible, and of the fourth comparatively dull and verging to apple green; the yellow of the second and third order are both good colours, but that of the second is especially rich and splendid; that of the first being a fiery tint passing into orange. The blue of the first order is so faint as to be scarce sensible, that of the second is rich and full, but that of the third much inferior; the red of the first order hardly deserves the name, it is a dull brick colour; that of the second is rich and full, as is also that of the third; but they all verge to crimson, nor does any pure scarlet, or prismatic red, occur in the whole series.

637. Law of the breadths of the rings and thicknesses at which they appear.

Phenomenon 2. The breadths of the rings are unequal. They decrease, and the colours become more crowded, as they recede from the centre. Newton (to whom we owe the accurate description and investigation of their phenomena) found by measurement the diameters of the *darkest* (or purple) rings, just when the central black spot began to appear by pressure, and reckoning it as one of them to be as the square roots of the even numbers 0, 2, 4, 6, &c.; and those of the brightest parts, of the several orders of colours, to be as the square roots of the odd numbers 1, 3, 5, 7, &c. Now the surfaces in contact being spherical, and their radii of curvature very great in proportion to the diameters of the rings, it follows from this that the intervals between the surfaces at the alternate points of greatest obscurity and illumination are as the natural numbers themselves 0, 1, 2, 3, 4, &c. The same measurements, when the radii of curvature of the contact surfaces are known, give the absolute magnitudes of the intervals in question. In fact, if r and r' be the curvatures of two spherical surfaces, a convex and concave, in contact, and D the diameter of any annulus surrounding their point of contact, the interval of the surfaces there will be the difference of the versed sines of the two circular arcs having a common chord D. Now (fig. 130) if A E be the diameter of the convex spherical surface A D, we have $\mathrm{EA} : \mathrm{AD} :: \mathrm{AD} : \mathrm{DB} = \frac{\mathrm{AD}^2}{\mathrm{AE}} = \frac{\mathrm{D}^2}{8} r$, and in like manner $\mathrm{BC} = \frac{\mathrm{D}^2}{8} r'$, so that $\frac{1}{8} \mathrm{D}^2 (r - r') = \mathrm{DC}$, the interval of the surfaces at the point D. Thus Newton found, for the interval of the surfaces at the brightest part of the first ring, one 178000dth part of an inch; and this distance, multiplied by the even natural numbers 0, 2, 4, 6, 8, &c. gives their distance at the black centre and the darkest parts of the purple rings, and by the odd ones 1, 3, 5, &c. their intervals at the brightest parts.

638. Invariable relation between the colours and thicknesses of plates.

Phenomenon 3. If the rings be formed between spherical glasses of various curvatures, they will be found to be larger as the curvatures are smaller, and *vice versâ;* and if their diameters be measured and compared with the radii of the glasses, it will be found, that, provided the eye be similarly placed, *the same colour is invariably produced at that point, or that distance from the centre where the interval between the surfaces is the same.* Thus, the white of the first order is invariably produced at a thickness of one 178000th of an inch; the purple, which forms the limit of the first and second orders, at twice that thickness. So that there is a constant relation between the tint seen and the interval of the surfaces where it appears. Moreover, if the glasses be distorted by violent and unequal pressure, (as is easily done if thin lenses be used,) the rings lose their circular figure, and extend themselves towards the part where the irregular pressure is applied, so as to form a species of level lines each marking out a series of points where the surfaces are equidistant. Thus, too, if a cylinder be laid on a plane, the rings pass into straight lines arranged parallel to its line of contact, but following the same law of distance from that line as the rings from their dark centre, and if the glasses be of irregular curvature, as bits of window glass, the bands of colour will follow all their inequalities; yet more, if the pressure be very cautiously relieved, so as to lift one glass from the other, the central spot will shrink and disappear, and so on; each ring in succession contracting to a point, and then vanishing, so as to bring all the more distant colours successively to the centre, as the glasses recede from absolute contact. From all these phenomena it is evident, that it is the distance between the surfaces only at any point which determines the colour seen there.

639. Effect of obliquity of incidence.

Phenomenon 4. This supposes, however, that we observe them with the eye similarly placed, or *at the same angle of obliquity*. For if the obliquity be changed by elevating or depressing the eye, or the glasses, the diameters (but not the colours) of the rings will change. As the eye is depressed, the rings enlarge; and the same tint which before corresponded to an interval of the 178000th of an inch, now corresponds to a greater interval. This distance ($\frac{1\text{ in}}{178000}$) is determined by measures taken nearly at, and reduced by calculation exactly to, a perpendicular incidence. At extreme obliquities, however, the diameters of the several rings suffer only a certain finite dilatation, and Newton's measures led him to the following rule: viz. "*That the interval between the surfaces at which any proposed tint is produced, is proportional to the secant of an angle whose sine is the first of* 106 *arithmetical mean proportionals between the sines of incidence and refraction, into the glass from the air, or other medium included between the surfaces, beginning with the greater*;" or, in algebraic language, the relative index of refraction being μ, and θ the angle of incidence, and ρ that of refraction of the ray as it passes out of the rarer medium into the denser; then, if t be the interval corresponding to a given tint at the oblique incidence θ, and T at a perpendicular incidence, we shall have

$$t = \mathrm{T} \,.\, \sec u \text{ where } \sin u = \sin\theta \frac{1}{107} - (\sin\theta - \sin\rho)$$

but $\sin\rho = \frac{1}{\mu} \,.\, \sin\theta$, consequently we have

$$t = \mathrm{T} \,.\, \sec u\,;\ \sin u = \frac{106 + \frac{1}{\mu}}{107} \,.\, \sin\theta \,. = \frac{106\,\mu + 1}{107\,\mu} \,.\, \sin\theta.$$

640. Fig. 132. Rings seen through a prism.

To see the rings conveniently at extreme obliquities, a prism may be used, laid on a convex lens, as in fig. 132. If the eye be placed at K, the set of rings formed about the point of contact E will be seen in the directions K H, and as the eye is depressed towards the situation I, where the ray I G intromitted from I would just begin to suffer total reflexion, the rings are seen to dilate to a certain considerable extent. When the eye reaches I, the upper half of the rings disappears, being apparently cut off by the prismatic iris of Art. 555, which is seen in that situation, but the black central spot and the lower half of the rings remains; but when the eye is still further depressed the rings disappear, and leave the central spot, like an aperture seen in the silvery whiteness of the total reflexion on the base of the prism, and dilated very sensibly beyond the size of the same spot seen in the position K H: thus proving, that the want of reflexion on that part of the base extends *beyond* the limits of *absolute contact* of the glasses, and that, therefore, the lower surface interferes with the action of the upper, and prevents its reflexion while yet a finite interval (though an excessively minute one) intervenes between them. Euler has made this an objection to the undulatory theory, but the objection rests on no solid grounds, as it is very reasonable to conclude, that the change of density or elasticity in the ether within and without a medium is not absolutely *per saltum*, but gradual. If so, and if the change take place *without* the media, the approach of two media within that limit, within which the condensation of the ether takes place, will alter the law of refraction from either into the interval separating them.

641. Fringes seen when a prism is laid on a plane glass. Fig. 133.

In order, however, to see to the greatest advantage the colours reflected by a plate of air at great obliquities, the following method, first pointed out by Sir William Herschel, may be employed. On a perfectly plane glass or metallic mirror, before an open window, lay an equilateral prism, having its base next the glass or mirror very truly plane, and looking in at the side A C, fig. 133, the reflected prismatic iris, *a*, *b*, *c*, will be seen as usual in the direction E F, where a ray from E would just be totally reflected. Within this iris, and arranged parallel to it, are seen a number of beautiful coloured fringes, whose number and distances from each other vary with every change of the pressure; their breadths dilating as the pressure is increased, and *vice versâ*. They do not require for their formation, that the surfaces should be exceedingly near, being seen very well when the prism is separated from the lower surfaces by the thickness of thin tissue paper, or a fine fibre of cotton wool interposed, but in this case they are exceedingly close and numerous. If the pressure be moderate, they are nearly equidistant, and are lost, as it were, in the blue iris, without growing sensibly broader as they approach it. As the intervals of the surfaces is diminished, they dilate and descend towards the eye, appearing, as it were, to come down out of the iris. They do not require for their formation a perfect polish in the lower surface. An emeried glass, so rough as to reflect no regular image at any moderate incidence, shows them very well. The experiment is a very easy one, and the phenomena so extremely obvious and beautiful, that it is surprising it should not have been noticed and described by Newton, especially as it affords an excellent illustration of his law above stated To understand this, let E H, E K, E L be any rays from E incident at angles somewhat less than that of total reflexion on the base; they will therefore be refracted, and, emerging at the base B C, will be reflected at M N, (the obliquity of the reflexion being so great, that even rough surfaces reflect copiously and regularly enough for the purpose, Art. 558,) and will pursue the courses H D P *p*, K F Q *q*, L G R *r*, &c. entering the prism again at P, Q, R. Reciprocally, then, rays *p* P, *q* Q, &c. incident at P, Q, &c. in these directions, Phenomena exhibited by homogeneous light.

number, and the more according to the degree of homogeneity of the light. When this is as perfect as possible, as, for instance, when we use the flame of a spirit lamp with a salted wick, as proposed by Mr. Talbot, they are literally innumerable, extending to so great a distance that they become too close to each other to be counted, or even distinguished by the naked eye, yet still distinct on using a magnifier, but requiring a higher and higher power as they become closer, till we can pursue them no farther, and disappearing from their closeness, and not from any confusion or running of one into the other. Moreover, they are now no longer composed of various colours, but are wholly of the colour of the light used as an illumination, being mere alternations of light and obscurity, and the intervals between them being absolutely black.

644.
Contraction of the rings in the less refrangible rays.

Phenomenon 6. When the illuminating light is changed from one homogeneous ray to another, as when, for instance, the colours of the prismatic spectrum are thrown in succession on the glasses at their point of contact, at such an angle as to be reflected to the eye, then, the eye remaining at rest, the rings are seen to dilate and contract in magnitude as the illumination shifts. In red light they are largest, in violet least, and in the intermediate colours of intermediate size. Newton, by measuring their diameters, ascertained that the interval of the surfaces or thickness of the plate of air, where the violet ring of any order was seen, is to its thickness, where the corresponding red ring of the same order is formed, nearly as 9 : 14; and, determining by this method, the thickness of the plate of air where the brightest part of the first ring was formed, when illuminated in succession by the several rays proceeding from the extreme red to the extreme violet, he ascertained those thicknesses to be the halves of the numbers already set down in the second column of the Table, p. 453, expressed in parts of an inch, and which answer to the values of $\frac{\lambda}{2}$, or the lengths of a semiundulation for each ray.

Analysis of the coloured rings.

645.
Synthesis of the coloured rings.
Fig. 134.

This phenomenon may be regarded as an analysis of what takes place when the rings are seen in white light; for in that case they may be regarded as formed by the superposition one on the other of sets of rings of all the simple colours, each set having its own peculiar series of diameters. The manner in which this superposition takes place, or the *synthesis* of the several orders of colours, may be understood by reference to fig. 134, where the abscissæ or horizontal lines represent the thicknesses of a plate of air between two glasses, supposed to increase uniformly, and where R R′, R R″, &c. represent the several thicknesses at which the red, in the system of rings illuminated by red rings only, vanishes, or at which the darkness between two consecutive red rings is observed to happen, while R *r*, R *r*′, R *r*″, &c. represent those at which the brightness is a maximum. In like manner, let 0 0′, 0 0″, &c. be taken equal to the several thicknesses at which the orange vanishes, or at which the black intervals in the system of orange rings are seen, and so on for the yellow, green, blue, indigo, and violet rings. So that R R′, 0 0′, Y Y′, &c. are to each other in the ratio of the numbers in column 2 of the above Table, (Art. 575.) Then if we describe a set of undulating curves as in the figure, and at any point, as C in A E, draw a line parallel to A V, cutting all these curves; their several ordinates, or the portions of this line intercepted between the curves and their abscissæ, will represent the intensity of the light of each colour, sent to the eye by that thickness of the plate of air. Hence, the colour seen at that thickness will be that resulting from the union of the several simple rays in the proportions represented by their ordinates.

646.
Synthesis of the several orders of colours.

The figure being laid down by a scale, we may refer to it to identify the colours of particular points. Thus, first at the thickness 0, or at A the origin of the tints, all the ordinates vanish, and this point, therefore, is black. As the thickness of the plate of air increases from 0 while yet very small, it is evident, on inspection, that the ordinates of the several curves increase with unequal rapidities, those for the more refrangible rays more rapidly than those for the less, so that the first feeble light which appears at a very small thickness A 1, will have an excess of blue rays, constituting the pure but faint blue of the first order, (Art. 635.) At a greater thickness, however, as A 2, the common ordinate passes nearly through the maxima of all the curves, being a little short of that of the red, and a little beyond that of the violet. The difference, however, is so small, that the several colours will all be present nearly in the proportions to constitute whiteness, and being all nearly at their maximum, the resulting tint will be a brilliant white. This agrees with observation; the white of the first order being, in fact, the most luminous of all; beyond this the violet falls off rapidly, the red increases, and the yellow is nearly at its maximum, so that at the thickness A 3 the white passes into yellow, and at a still greater thickness, A 4, where the violet, indigo, blue, and green, are all nearly evanescent, the yellow falling off, and the orange and red, especially the latter, in considerable abundance, the tint resulting will be a fiery orange, growing more and more ruddy. At B is the minimum of the yellow, *i. e.* of the most luminous rays. Here then will be the most sombre tint. It will consist of very little either of orange, green, blue, or even indigo; but a moderate portion of violet and a little red will produce a sombre violet purple, which, since the more refrangible rays are here all on the increase, while the less are diminishing, will pass rapidly to a vivid blue, as at the thickness denoted by A 5. At 6, where the ordinate passes through the maximum of the yellow, there is almost no red, very little orange, a good deal of green, very little blue, and hardly any indigo or violet. Here then the tint will be yellow verging to green, but the green is diminishing and the orange increasing, so that the yellow rapidly loses its green tinge, and becomes pure and lively. At 7 the predominant rays are orange and yellow, being so copious that the little red and violet with which they are mixed does not prevent the tint from being a rich, high-coloured yellow. At 8 a full orange and copious red are mixed with a good deal of indigo and a maximum of violet, thus producing a superb crimson. At C we have again a minimum of yellow; but there being at the same time a maximum of red and indigo, this point, though dark in comparison of that on either side, will still be characterised by a fine ruddy purple. This completes, and as we see faithfully represents, the second order of colours. At 9, 10 we see the origin of the vivid green of the third order, in the comparative copiousness of green, yellow, and blue rays at the former point, and of yellow, green,

655. Explanation of the rings seen by homogeneous light.

Let us now consider what will happen to a luminous molecule, the length of whose fits in any medium is $\frac{1}{2}\lambda$, which, having been intromitted perpendicularly at the first surface, and traversing its thickness ($= t$), reaches the second. First, then, if we suppose t an exact multiple of $\frac{1}{2}\lambda$, it is evident that the molecule will arrive at the second surface in precisely the same phase of its fit of transmission as at the first. Of course it is placed in the very same circumstances in every respect, and having been transmitted before must necessarily be so again. Thus every ray which enters perpendicularly into such a lamina must pass through it, and cannot be reflected at its second surface. On the other hand, if the thickness of the lamina be supposed an exact odd multiple of $\frac{1}{4}\lambda$, &c. every molecule intromitted at its first surface will on its arrival at the second be in exactly the contrary phase of its fits, and, having been before in some phase of a fit of transmission, will now be in a similar phase of a fit of reflexion. It will, therefore, not necessarily be transmitted; but a reflexion, more or less copious, will take place at the second surface in this case, according to the nature of the medium and its general action on light. For it will be remembered, that every molecule in a fit of reflexion is not *necessarily* reflected. It is disposed to be so; but whether it will or no, will depend on the medium it moves in and that on which it impinges, and on the phase of its fit. Now conceive an eye placed at a distance from a lamina of unequal thickness, so as to receive rays reflected at a very nearly perpendicular incidence from it. It is evident, that in virtue of the reflexion from the first surface, which is uniform, it will receive equal quantities of light from every point. But with regard to the light reflected from the second the case is different; for in all those parts where the thickness of the lamina is an exact even multiple of $\frac{1}{4}\lambda$, *none* will be reflected, while in all those where it is an exact odd multiple of $\frac{\lambda}{4}$, a reflexion will take place; and since each molecule so reflected *retraces the path by which it arrived*, and therefore describes again the same multiple of $\frac{\lambda}{4}$; its total path described within the lamina, when it has reached the first surface again, will be an exact multiple of $\frac{\lambda}{2}$, and therefore it will penetrate that surface and reach the eye. In consequence, in virtue of the reflexion at the second surface alone, the lamina would appear black in every part where its thickness $= 0$, or $\frac{2\lambda}{4}$, or $\frac{4\lambda}{4}$, &c., and bright in those parts where its thickness $= \frac{1\lambda}{4}$, or $\frac{3\lambda}{4}$, $\frac{5\lambda}{4}$, &c. *ad infinitum.* In the intermediate thicknesses it would have a brightness intermediate between these and absolute obscurity; so that on the whole, the lamina would appear marked all over with dark and bright alternating fringes, just as we see it actually does in the experiment described, (Art. 649.) The uniform reflexion from the first surface superposed on these, will not prevent their inequality of illumination from being distinctly seen.

656. Of the rings seen by white light.

Hence it is evident, that if we take the abscissa of a curve equal to thickness of the lamina at any point, and the ordinate proportional to the intensity of the light reflected from the second surface, and returned through the first, this curve will be an undulating line, such as we have represented in fig. 134, touching the abscissa at equal distances equal to the length of a whole fit of a ray of the colour in question. Now these distances for rays of different colours being supposed such as we have assumed in Art. 652, the construction of Art. 645 holds good, and when white light falls on the lamina, its second surface will reflect a series of colours of the composition there demonstrated, and such as we actually observe, but diluted with the light uniformly reflected from every point of the first surface.

If the lamina instead of a vacuum be composed of any refracting medium, the tints will manifestly succeed each other in a similar series, but the thickness at which they are produced will be to that in a lamina of vacuum, in the ratio of the lengths of the fits in the two cases, that is, in the proportion of 1 : the index of refraction of the medium. Thus the rings seen between two object glasses including air, ought to contract when water, oil, &c. is admitted between them, as they are found to do, and, by measure, in that precise ratio.

657. Of the dilatation of the rings at oblique incidences.

At oblique incidences, θ being the angle of intromission into the lamina, $t \,.\, \sec\theta$ is the whole path of the ray between the first and second surfaces, and since $\frac{1}{2}\lambda \,.\, \sec\theta \,.\, \sec u$ is the length of the fits of the given ray at this obliquity, in order that the luminous molecule may arrive at the second surface in the same phase, and therefore be reflected with equal intensity, it must in this space have passed over the same number of these fits; hence we must have $\frac{2t \,.\, \sec\theta}{\lambda \,.\, \sec\theta \,.\, \sec u} =$ constant, or t proportional to $\sec u$, which agrees with observation

658. Of the transmitted rings.

All the light which is not reflected at the second surface passes through it, and forms the transmitted series of colours. These, therefore, consist of the whole incident light ($= 1$) *minus* that reflected at the first surface, (which will be a small fraction, and which we will call a,) *minus* that reflected at the second surface. Now this last will be a periodical function whose minimum is 0, and its maximum can never exceed a, because the reflexion at the second surface of a medium cannot be stronger than at the first at a perpendicular incidence. We may then represent it by $a\left(\sin\frac{2t}{\lambda}\right)^2$, and thus we have $1 - a\left\{1 + \left(\sin\frac{2t}{\lambda}\right)^2\right\}$ for the intensity of this particular coloured ray in the transmitted series, and $a\left(\sin\frac{2t}{\lambda}\right)^2$ in the reflected. Hence it is evident, that owing to the smallness of a, the difference between the brightest and darkest part of the transmitted series will be small in comparison with the whole light, and thus the alternations in homogeneous light ought to be (as they are) much less sensible than in the reflected rings, and the tints in white light much more pallid and dilute.

659. Thus we see that the Newtonian hypothesis of the fits affords a satisfactory-enough explanation, or rather represents with exactness all the phenomena above described. It has been even asserted, that this doctrine is really not an hypothesis, but nothing more than a pure statement of facts; for that, first, in point of mere fact, the second surface of the lamina does send light to the eye, in the bright parts of the fringes, and does not send it in the dark parts; and, secondly, that this is the same thing with saying that the light which has traversed thickness $= (2\,n + 1)\,\frac{\lambda}{4}$ is, and that which has traversed $2\,n\,\frac{\lambda}{4}$ is not susceptible of being reflected. And in truth, if only one ray could be regarded as being concerned, and were the light reflected at the first surface of the lamina altogether out of the question, this way of stating it would be strictly correct. But, if it can be shown, that, on any other hypothesis of the nature of light, (as the undulatory,) the second link of this argument is invalid; and that though the second surface, like the first, may reflect in every part, without regard to its thickness, its full average portion of the light that is incident on it; *yet* that afterwards, by reason of the interference of rays reflected from the first surface, such light does *not* reach the eye (being destroyed in every point of its course) from those parts where the thickness is an even multiple of $\frac{\lambda}{4}$, then it is evident, that the Newtonian doctrine is something more than a mere *aliter* statement of facts, and is open to examination as a theory.

660. Explanation of the transmitted rings on the undulatory hypothesis.

Let us now see, therefore, what account the undulatory theory gives of these phenomena. We will begin, for a reason which will presently appear, with the *transmitted* rings. Conceive, then, a ray, the length of whose undulations in any medium is λ, to be incident perpendicularly on the first surface of a lamina of that medium whose thickness is $= t$; and (for simplicity) let its surfaces be supposed parallel, then it will be divided into two portions, the first ($= a$) reflected, and the second ($= 1 - a$) intromitted. Let θ be the phase of this portion at reaching the second surface. Here it will be again divided into two portions, the one reflected back into the medium and equal to $(1 - a)\,.\,a$, or (a being small) very nearly to a, and the remainder $(1 - a) - a\,(1 - a)$, or nearly $1 - 2\,a$, transmitted. These portions, supposing no undulation, or part of an undulation, gained or lost in the act of transmission or reflexion, will both be in the phase θ. The reflected portion will again encounter the first surface in the phase $\theta + 2\,\pi\,.\,\frac{t}{\lambda}$, will there be again partially reflected, with an intensity equal to $a \times a = a^2$, and the portion so reflected will reach the second surface in the phase $\theta + 2\,\pi\,.\,\frac{2\,t}{\lambda}$, and will there be transmitted with an intensity $= (1 - a)\,.\,a^2$, or nearly $= a^2$. Now, the reflexions being all perpendicular, this portion will be confounded with the portion $1 - 2\,a$ transmitted without any reflexion; and putting $\alpha = \sqrt{1 - 2\,a} = 1 - a$ nearly, and $\alpha' = \sqrt{a^2} = a$, α and α' will represent the amplitudes of vibration of the ethereal molecule at the posterior surface, which each of these rays tend to impress on it. Hence, its total excursion from rest will be represented by

$$\alpha\,.\,\cos\theta + \alpha'\,.\,\cos\left(\theta + 2\,\pi\,.\,\frac{2\,t}{\lambda}\right),$$

that is

$$(1 - a)\cos\theta + a\,.\,\cos\left(\theta + 2\,\pi\,.\,\frac{2\,t}{\lambda}\right).$$

$$= 1\cos\theta + a\,.\,\cos\left(\theta + 2\,\pi\,.\,\frac{2\,t}{\lambda}\right) - a\,.\,\cos\theta.$$

The first term of this is independent of t, and represents, in fact, the incident ray in the state in which it would arrive at the second surface, had no reflexions taken place. The other two terms represent rays the former of which evidently is in complete discordance with the latter, and destroys it when t is any odd multiple of $\frac{\lambda}{4}$, (or of the half length of one of Newton's fits, a fit being, as we have seen above, equal to half an undulation,) thus leaving the ray at its emergence of the same intensity as it would have had were the lamina away; but when t is any odd multiple of half a fit, then the value of $\cos\left(\theta + 2\,\pi\,.\,\frac{2\,t}{\lambda}\right) = -\cos\theta$; and the emergent ray is in this case represented by $(1 - 2\,a)\,.\,\cos\theta$, being less than the incident ray by twice the light reflected at the first surface.

661. Origin of the bright and dark rings in homogeneous light.

Thus if the thickness of the plate be different in different parts, the light transmitted through it to the eye will not be uniform, but will have alternate maxima and minima corresponding to the thicknesses 0 $\frac{\lambda}{4}$, $\frac{2\,\lambda}{4}$, $\frac{3\,\lambda}{4}$, &c.

If we apply to the expression above given, the general formula Art. (613) for the composition of rays in one plane, we shall find for the intensity A^2 of the ray finally emergent,

662. General expression for the transmitted ray.

$$A^2 = (1 - a)^2 + 2\,a\,(1 - a)\,.\cos 2\,\pi\,.\,\frac{2\,t}{\lambda} + a^2$$

$$= 1 - 4\,a\,(1 - a)\,.\sin\left(2\,\pi\,\frac{t}{\lambda}\right)^2$$

$$= 1 - 4\,a\,.\sin\left(2\,\pi\,\frac{t}{\lambda}\right)^2$$

which shows that the several maxima are equal to the incident ray, and the minima to that ray diminished by four times the light reflected at the first surface. The difference of phase between the simple and composite emergent ray, or the value of B in the formula cited, is given by the equation,

$$\sin B = \frac{a}{A}\,.\sin\left(2\,\pi\,.\,\frac{2\,t}{\lambda}\right) = a\,.\sin\left(2\,\pi\,.\,\frac{2\,t}{\lambda}\right),\ \text{neglecting } A^2,$$

so that for such media as have not a very high refractive power, this difference is always small. It is, however, periodical, and differs for different thicknesses.

663. Transmitted tints in white light expressed algebraically.

Suppose now, instead of homogeneous light, white light to fall on the lamina, and let us represent a ray of such light, as in Art. 488, by $C + C' + C'' +$ &c., or by $S\,(C)$, C, C', &c. being the intensity of the several elementary rays of all degrees of refrangibility, then will the transmitted compound beam be represented in tint and intensity by

$$C\left\{1 - 4\,a\,.\sin\left(2\,\pi\,\frac{t}{\lambda}\right)^2\right\} + C'\left\{1 - 4\,a\,.\sin\left(2\,\pi\,.\,\frac{t}{\lambda'}\right)^2\right\} + \&c.$$

or by

$$S\,.\,C\left\{1 - 4\,a\,.\sin\left(2\,\pi\,\frac{t}{\lambda}\right)^2\right\}.$$

Now this is the same with

$$S\left\{C\,(1 - 4\,a) + C\,(4\,a - 4\,a\,.\sin\left(2\,\pi\,.\,\frac{2\,t}{\lambda}\right)^2\right\} =$$

$$= (1 - 4\,a)\,.\,S\,(C) + 4\,a\,.\,S\left\{C\,.\cos\left(2\,\pi\,.\,\frac{2\,t}{\lambda}\right)^2\right\}.$$

The first term of this expression represents a beam of white light of the intensity $1 - 4\,a$. The second, a compound tint of the intensity $4\,a$, which, diluted with the above-mentioned white light, forms the pallid tints of the transmitted series. If we disregard this dilution, and consider only the tint in its purity as it would appear were the white light suppressed, its expression

$$4\,a\,.\,S\left\{C\,.\cos\left(2\,\pi\,.\,\frac{2\,t}{\lambda}\right)^2\right\} = 4\,a\left\{S\,(C) - S\left(C\,.\sin\left(2\,\pi\,.\,\frac{2\,t}{\lambda}\right)^2\right)\right\}$$

indicates that it is *complementary* to the tint represented by

$$S\left\{C\,.\sin\left(2\,\pi\,.\,\frac{2\,t}{\lambda}\right)^2\right\}.$$

But if we conceive a curve whose abscissa $= t$, and whose ordinate is $C\,.\sin\left(2\,\pi\,.\,\frac{2\,t}{\lambda}\right)^2$, it is evident that this will be precisely the undulating curve represented for each prismatic ray in fig. 134; and taking the sum of all the ordinates so drawn for each colour in the spectrum, we have the identical construction from which we derived the colours of the reflected rings in Art. 645. If, then, we take the series of tints so composed, and thence deduce their complements to white light, and dilute these complementary colours with white, in the proportion of $4\,a$ rays of the complementary colour to $1 - 4\,a$ of white, we shall have the series of transmitted tints which ought to result from the doctrine of interferences, and which, in fact, is observed.

664. Case of oblique transmission Fig. 135.

In the case of oblique transmission, let A C, B D, fig. 135, be the surfaces of the lamina, and A a its thickness; and let A E be the surface of a wave of which the point A has just reached the first surface of the lamina; and let S A, S C, perpendicular to it, represent rays emanating from one origin S, then will a partial reflexion take place, and its intensity will be diminished in some certain ratio $1 : 1 - a$ depending on the angle of incidence. The transmitted wave will be bent aside, taking the position A b, and advancing along A B the refracted ray; so that when it reaches the position B F, the wave without the lamina will have the corresponding position F G. Here another partial reflexion will take place depending on the interior incidence, and we may denote by $(1 - a)\,(1 - a)$ the transmitted portion, and by $(1 - a)\,.\,a$ the reflected portion. These portions set off together, from B, the former, with the velocity V due to the exterior medium, along the line B H parallel to S A, forming a wave which (provided S be sufficiently distant) may be regarded as a plane of indefinite extent moving uniformly with that velocity along B H. The latter portion proceeds along B C, according to the law of reflexion, with the velocity V′ due to the medium of which the lamina is composed till it reaches C, where it undergoes another partial reflexion, and proceeds back along the line C D with a diminished intensity $= (1-a)$

$$\sec u = \sec \rho \left\{ 1 - \frac{1}{2} \cdot \frac{106}{107} (\mu - 1) \cdot \tan \rho^2 \right\},$$

which does not deviate very greatly from sec ρ at moderate incidences.

670. Deviation from Newton's rule at great obliquities probably accounted for.

At great incidences the case is different, and the noncoincidence of the results of the undulatory doctrine with experiment might be drawn into an argument against it, were we sure that the law of refraction at extreme incidences, and with very thin laminæ, does not vary sensibly from that of the proportional sines. This is, indeed, highly probable, as M. Fresnel has remarked, (*Mém. sur la Diffraction, &c.*) and as we have before had occasion to observe. The inquiry into which this would lead, is, however, one of the most delicate and difficult in physical optics, and the reader must be content with this general *notice* of a *possible* explanation of one of the many difficulties which still beset the undulatory doctrine.

671. Origin of the reflected rings.

The origin of the reflected rings may be accounted for in a similar way from the partial transmission of the waves reflected from the second surface back through the first, and their interference with the waves reflected immediately from the first. The relative intensities of these waves, (in general,) are a and $(1 - a)\ (1 - \alpha) . \alpha$; or, in the case where a and α are both small, nearly in the ratio of $a : \alpha$, and at a perpendicular incidence, very nearly in the ratio of equality. Hence their mutual destruction in the case of complete discordance will be much more complete than in the transmitted rings, and the colours arising, much less dilute than those of the latter, agreeably to observation.

672. Loss of half an undulation.

There is, however, one consideration of importance to be attended to in the application of the undulatory doctrine to the reflected rings, which at first sight appears in the light of a powerful argument against its admissibility, *viz.* that if we apply the same reasoning to the reflected, as we have already done to the transmitted, rings, we should arrive at the conclusion, that their tints should be *precisely the same* and in the same order, beginning with a bright white in the centre; because *here*, the path traversed by the ray within the lamina vanishing, the waves reflected from the two surfaces ought to be in exact accordance, whereas it appears, by observation, that the reverse is the case, the central spot being black instead of white. It becomes necessary, then, to suppose, that in this case, half an undulation is lost or gained either by the wave reflected from the first or second surface. If this hypothesis be made, the phenomena of the reflected rings are completely represented on the undulatory system, for the compound wave reflected by the joint action of the two surfaces should be represented by the equation,

$$X = \sqrt{a} . \cos \theta + \sqrt{\alpha\ (1 - a)\ (1 - \alpha)} . \cos \left\{ \theta + 2\pi . \frac{2t' - \frac{1}{2}\lambda}{\lambda} \right\}$$

and if this be put equal to A . cos $(\theta + B)$ we get

$$A^2 = a + \alpha\ (1 - a)\ (1 - a) - 2 \sqrt{a\,\alpha\ (1 - \alpha)\ (1 - a)} . \cos \left(2\pi \frac{2t'}{\lambda} \right)$$

and in the case of a and α both very small

$$A^2 = (\sqrt{a} - \sqrt{\alpha})^2 + 4 . \sqrt{a\,\alpha} . \sin \left(2\pi \frac{t'}{\lambda} \right)^2$$

and at a perpendicular incidence, where $t' = t$, and where α and a may be supposed equal

$$A^2 = 4\,a . \sin \left(2\pi \frac{t}{\lambda} \right)^2$$

673. Not contrary to dynamical principles

Thus we see, that in this case the total intensity of the compound reflected wave + that of the transmitted (Art. 662) make up 1, the intensity of the incident wave; and thus, this supposition of the loss or gain of half an undulation is in no contradiction with the law of the conservation of the *vis viva*.

674. Nor to the undulatory doctrine.

In fact, however, if we consider the mode in which the undulations are propagated, at the limit between two media, we shall see nothing contrary to dynamical principles in the loss of half or any part of an undulation in the transfer—for it cannot be supposed, that the density or elasticity of the ether changes abruptly at the surfaces of media, but that there intervenes some very minute stratum in which it is variable. In this stratum, therefore, the length of an undulation is neither exactly that corresponding to the denser, nor to the rarer medium, but intermediate, and of a magnitude perpetually varying. Therefore the number of undulations *to be reckoned as added to the phase* of the ray *in traversing this stratum,* will differ from what it would be if one medium terminated, and the other commenced abruptly. Without knowing the law of density, the limits between which it undergoes its change, or the exact mode in which the partial reflexion of a wave traversing it is performed, it is impossible to subject the point to strict calculation, we must rather submit to be taught by experiment, and content ourselves with such conclusions as we can deduce from observation. In the case before us, all that observation teaches us is, that there is half an undulation more of difference in the phases of two rays that have been reflected in the manner last considered, than in those of the two whose interference forms the transmitted rays. From some curious experiments of Dr. Young, too, we may gather that it is not in all cases *strictly half* an undulation of difference to be reckoned, but rather a variable fraction depending on the nature of the contiguous media.

The formulæ of Art. 672 show that it is only in the case of perpendicular incidence that the tints are pure,

675. and that in all others, and especially at great obliquities, where a and α differ considerably, there will be a

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dilution of white light, and this is also agreeable to experience. At a perpendicular incidence, however, the minima of each homogeneous colour ought to be absolutely evanescent; so that if we were to remove the reflection of the upper surface of an object glass laid down on a plate, (or use a prism, so as to prevent its reaching the eye,) the intervals between the rings in homogeneous light ought to appear absolutely black. In the Newtonian doctrine this should not be the case, because the light reflected from the upper surface of the lamina of included air should still remain even in the minima of the rings. This then affords a positive means of deciding between the two theories. M. Fresnel describes an experiment made for this purpose, and states the result to be unequivocally in favour of that of undulations. (*Diffraction de la Lumière*, p. 11.)

Experimentum crucis between the two theories

§ V. *Of the Colours of Thick Plates.*

676 Under certain circumstances rings of colours are formed by plates of transparent media of considerable thickness. The circumstances under which they appear, in one principal case, are thus described by Newton, who first observed them, and who has applied his doctrine of the fits of easy reflexion and transmission to explain them, with singular ingenuity.

Newton's experiment with a glass mirror.

"Admitting a bright sunbeam through a small hole of one-third of an inch in diameter into a dark room, it was received perpendicularly on a concavo-convex glass mirror one quarter of an inch thick, having each surface ground to a sphere of six feet in radius, and the back silvered. Then holding a piece of white paper in the centre of its concavity, having a small hole in the middle of it to let the sunbeam pass, and after reflexion at the speculum to repass through it, the hole was observed to be surrounded with four or five coloured concentric rings or irises, just as the rings seen between object-glasses surround their central spot—but larger and more diluted in their colours".... "If the paper was much more distant from the mirror, or much less than six feet, the rings became more dilute and gradually vanished.".... "The colours of these rings succeeded each other in the order of those which are seen between two object glasses, not by reflected but by transmitted light, viz. white, tawny white, black, violet, blue, greenish yellow, yellow, red, purple," &c..... "The diameters of these rings preserved the same proportion as those between the object-glasses, the squares of the diameters of the alternate bright and dark rings, reckoning the central white as a ring of the diameter 0, forming an arithmetical progression, beginning at 0. And in the case described, the diameter of the bright ring measured respectively 0, $1\frac{11}{16}$, $2\frac{3}{8}$, $2\frac{11}{12}$, $3\frac{3}{8}$.".... "Lastly, in the rings so formed by reflectors of different thicknesses, their diameters were observed to be reciprocally as the square roots of the thicknesses. If the back of the mirror was silvered, the rings were only so much the more vivid."

677 These various phenomena, and a variety of similar ones, some of more, some of less complexity, according to the variation of the distance, and obliquity of the mirror, and the curvature of its surfaces, Newton has explained very happily, by considering the fits of easy reflexion and transmission of that faint portion of the light which is irregularly *scattered* in all directions at the first surface of the glass, and which serves to render it visible. But for this explanation we must refer to his *Optics*, as our object here is more particularly and distinctly to show what account the undulatory doctrine gives of this phenomenon, which has hitherto been passed over rather cursorily, not without some degree of obscurity.

678. Principle of explanation on the undulatory system.

There is no surface, however perfectly polished, so free from small scratches and inequalities as not to reflect and transmit, besides those principal rays which obey the regular laws of reflexion and refraction, as dependent on the general surface, other, very much feebler, portions scattered in all directions, by which the surface is rendered visible to an eye anywhere placed, but most copiously in and about the direction of the regularly reflected and transmitted rays. It is the interference of these portions, scattered at the first surface by the ray in passing and repassing through it, nearly in its own direction, that the rings in question are attributed in the undulatory doctrine.

679. Its application. Fig. 136.

Let F A D, E B G be the parallel surfaces of any medium exposed perpendicularly to a homogeneous ray emanating from a luminous point C, and incident at A. The chief portion will pass straight through A, and be reflected back from B to A again. But at A a scattering takes place, and the transmitted ray A B is accompanied by a diverging cone of faint rays A *a*, A *b*, A *c*, &c., all which set out from A in the same phase of their undulations with the principal one from which they originate, so that A may be regarded as their common origin. Take Q, the focus of rays reflected at the second surface conjugate to A (if the surfaces be plane, Q and A are equidistant from B) and the cone of scattered rays, with the regularly reflected ray in its axis, will after reflexion diverge as from Q. Again, when they pass into the air again, if we take *q* the focus conjugate to Q of rays refracted at the surface F D, they will after refraction diverge from *q*, and by the nature of foci on the undulatory hypothesis, the undulations will be propagated in the air as if they had a common origin *q placed in air;* because, after refraction, the waves have the form of spheres diverging from *q*, and therefore every portion of their surfaces are equidistant from *q;* had they, therefore, really emanated from *q*, as separate rays, they must at the moment of such emanation have been all in one phase. Now, when the reflected beam reaches A a portion of it will again be scattered in a cone, having the regularly transmitted ray A G in its axis; and the rays A O, A N, A M, &c. of this cone will all have A for their origin, and will be in the same phase at their departure from A with the ray A G; but this is in the phase it would have had as emanated from *q;* hence, if we consider any point M out of the directly transmitted ray A G, it will be reached at once by a wave belonging to each diverging cone, the one along *q* M from *q* and the other along A M from A, and the difference of routes is equal to $q\text{A} + \text{AM} - q\text{M}$. Therefore, when M is very nearly coincident with G, this is very small and at G vanishes, or the waves are in exact accordance. As M recedes from G it increases, and when it becomes half an undulation, the waves are in complete discordance and annihilate each other, and so on alternately. Therefore, as this is true of all rays in conical surfaces round A G as an axis, equally inclined with A M, q M, if we place a white screen at G, it will appear marked with alternate dark and bright rings round a bright centre. To determine their diameters we need only put $q\,\mathrm{A} + \mathrm{A\,M} - q\,\mathrm{M} = n\,.\,\frac{\lambda}{2}$, or, if we take $q\,\mathrm{A} = a$, $\mathrm{A\,G} = r$, $\mathrm{G\,M} = y$,

$$a + \sqrt{r^2 + y^2} - \sqrt{(a+r)^2 + y^2} = n\,\frac{\lambda}{2}$$

If we resolve this equation neglecting y^2, we find

$$y = \sqrt{n}\,.\,\sqrt{\frac{\lambda}{a}\,.\,r\,(a+r)}$$

which, on substituting 0, 1, 2, 3, &c. in succession for n, shows that the successive diameters of the alternate dark and bright rings are in the progression of the square roots of those numbers.

680. Law of the diameters of the rings. If the thickness of the plate be small compared to the distance of the screen, a will also be small, and the value of y becomes

$$y = r\,.\,\sqrt{n}\,.\,\sqrt{\frac{\lambda}{a}},$$

which shows that for rays of a given refrangibility the diameters of the rings are as the distance of the screen directly, and the square root of the thickness of the plate inversely.

681. Of their colours. Lastly, the diameter of a ring of the same order in different homogeneous lights, are as the square roots of the lengths of their undulations. Now, this is the very same law that governs the diameters of the rings formed between object-glasses. Consequently, if instead of homogeneous we consider white light, we ought to have a succession of coloured rings whose tints agree precisely with the transmitted series in that experiment.

682. Concentration of the rings from all points of the surface. Fig. 137. But the rays so formed, by rays scattered from a single point A, would be too feeble to be visible. If, however, we suppose the surfaces to be concentric spheres having G in their common centre, as in fig. 137, then any rays G A, G A′ falling on any points whatever of their surfaces will depict, on screens G M, G M′ respectively perpendicular to them as G, equal systems of rings having G in their common centre; and, when the arc A A′ is not very great, the screens may be regarded as coincident (for in that case B M − M A = B M′ − M A′) and the rings from every point of the surface, exactly superposed on each other, and being thus increased in intensity in proportion to the area of the exposed surface, become visible.

683. Newton's experiment particularly considered. Now this is exactly Newton's case, for the sun being a luminary of a considerable diameter, the hole in the centre of the spheres may be regarded as a portion of the sun of that size, actually placed there. Of this, every indivisible point may be regarded as the origin of a system of waves, and as depicting on the screen its own set of rings. These, were the hole infinitely small, would be infinitely more clear and pure in their tints than the transmitted rings between object-glasses, because they are not (as in those rings) diluted with the great quantity of white light which escapes interference. But owing to the size of the hole, their centres are not exactly coincident, and therefore their tints mix and dilute each other, and that the more the larger the hole is.

684. If c be the thickness of the glass, since Q is the conjugate focus of A, on the surface B whose radius we will call $r + c$ putting $\mathrm{G\,A} = r$, we have, by Art. 249, $\mathrm{B\,Q} = \frac{r+c}{r-c}\,.\,c$, $\mathrm{A\,Q} = \frac{2\,r\,c}{r-c}$; and, by Art. 248, $\mathrm{A}\,q = a = \frac{2\,c\,r}{2\,c - \mu\,(r+c)}$, taking μ for the refractive index; and when c is small compared with r, we get

$$a = \frac{2\,c}{\mu}\,;\ y = r\,.\,\sqrt{n}\,.\,\sqrt{\frac{\mu}{2}\,.\,\frac{\lambda}{c}}$$

showing that the diameters of the rings are in this case in the subduplicate ratio of the refractive index of the glass directly, and of its thickness inversely.

685 If we reduce this value to numbers, taking $\mu = \frac{3}{2}$, $n = 4$, $r = 6$ feet $= 72$ inches, and $\lambda = \frac{2}{89000} =$ the length of an undulation for yellow rays $\frac{2}{90000}$ nearly, we find, for the diameter of the second bright ring in yellow light, (which corresponds to the brightest part of the same ring in white,)

$$2\,y = 72 \times \sqrt{4\,.\,\frac{3}{4}\,.\,\frac{2}{90000}\,.\,4} = 2{\cdot}35,$$

which agrees almost precisely with Newton's measure $2\frac{3}{8}$, or 2·375.

686 Case of oblique incidence. When the mirror is inclined to the incident beam the phenomena become more complicated, and have been elegantly described by Newton, (*Optics,* book ii. part iv. obs. 10.) In this case, the axes of the two interfering cones of scattered rays, which are always the incident and reflected rays, are no longer coincident. But the same principles apply equally to this case in all other respects, and the reader may exercise himself in tracing their consequences.

687. Phenomena observed by the Duke of Chaulnes and The Duke de Chaulnes found similar rings to be exhibited when the surface of the mirror was covered with a thin film of milk dried on it, so as to make a delicate semitransparent coating, or even when a fine gauze or muslin was stretched before it; see the account of his experiments in the *Mém. Acad. Sci. Paris,* 1705; and

Sir W. Herschel.

Sir William Herschel (*Phil. Trans.* 1807) describes a pleasing experiment, in which rings were produced by strewing hair powder in the air before a metallic mirror on which a beam of light is incident, and intercepting the reflected ray by a screen. The explanation of these phenomena seems, however, to depend on other applications of the general principle, and will be better conceived when we come to speak of the colours produced by diffraction.

688. Dr. Brewster's fringes seen in thick plates.

Dr. Brewster, in the *Transactions of the Royal Society of Edinburgh*, has described a series of coloured fringes produced by thick plates of parallel glass, which afford an excellent illustration of the laws of periodicity observed by the rays of light in their progress, whether, as in the Newtonian doctrine, we consider them as subjected to alternate fits of easy reflexion and transmission, or, as in the undulatory hypothesis, as passing through a series of phases of alternately direct and retrograde motions in the particles of ether, in whose vibrations they consist. We may here remark, once for all, that the explanations which the undulatory doctrine affords of phenomena of this description, may, for the most part, be translated into the language of the rival hypothesis; so as to afford, with more or less plausibility and occasional modifications, a result corresponding with observation. It is not, therefore, among phenomena of this class that we must look for the means of deciding between them. We shall adopt, therefore, in the remainder of this essay, the undulatory system, not as being at all satisfied of its reality as a *physical fact*, but regarding it as by far the simplest means yet devised of grouping together, and representing not only all the phenomena explicable by Newton's doctrine, but a vast variety of other classes of facts to which that doctrine can hardly be applied without great violence, and much additional hypothesis of a very gratuitous kind.

689. Described.

The fringes in question are seen when two parallel plates of glass of exactly equal thickness (portions of the same plate) are slightly inclined to each other, (at any distance,) and through them both, at nearly a perpendicular incidence, a circular luminary of 1° or 2° in diameter (a portion of the sky, for instance) is viewed. There will in this case be seen, besides the direct image, a series of lateral images reflected between the glasses, and growing fainter and fainter in succession as they are formed by 2, 4, 6, or more internal reflexions; and of which all but the first is so faint as scarcely to be visible, except in very strong lights. The direct image is colourless; but the reflected one is observed to be crossed with fifteen or sixteen beautiful bands of colour, parallel to the common section of the surfaces of the plates. Their breadth diminishes rapidly as the inclination of the plates increases. When the plates employed were 0.121 inch in thickness, and inclined at an angle of 1° 11′ to each other, the breadth of each fringe measured 26′ 50″, and at all other inclinations their breadth was inversely as the inclination. At oblique incidences its fringes are seen when the plane of incidence is at right angles to the principal section of the plates, but are at their maximum of distinctness when parallel to it.

690. Explained.

To understand their production, let us call the surfaces of the plates in order, reckoning from that on which the incident light first falls, A, a, B, b; and let us consider a ray, or system of waves emanating from a common origin at an infinite distance. Then, when this ray falls on the plates it will at every surface undergo a partial reflexion, and the remainder will be transmitted; each of the several portions will be again subdivided whenever it meets either surface. So that either image will, in fact, consist of several emergent rays, parallel in their final directions, but which have traversed the glasses by very different routes. Thus the direct or principal image will consist of

1. The chief portion of the whole incident light, refracted at A, at a, at B, and at b, and emergent parallel to the incident ray, which we will represent by $A\,a\;B\,b$.

2. A portion refracted at A, reflected at a, reflected again at A, refracted again at a, at B and at b, and emergent parallel to the incident beam. This we will denote thus, $A\,a'\,A'\,a\,B\,b$; the letters denoting the surfaces, the accent reflexion, and its absence refraction.

3. A portion which has undergone two similar reflexions in the interior of the second plate, and which in the same manner may be represented by $A\,a\,B\,b'\,B'\,b$.

4. Other portions which have undergone respectively four, six, &c. reflexions to infinity within either of the plates, and which may be represented by such combinations as $A\,a'\,A'\,a'\,A'\,a\,B\,b$, $A\,a\,B\,b'\,B'\,b'\,B'\,b$, or, for brevity, by $A\,(a'\,A')^2\,a\,B\,b$, $A\,a\,B\,(b'\,B')^2\,b$, &c.; but these latter portions are too faint to have any sensible influence on the light of the direct image with which they are confounded.

The first lateral reflected image will consist of four principal portions which have undergone two reflexions each, *viz.* 691.

$$A\,a\,B'\,a'\,B\,b;\qquad A\,a\,B'\,a\,A'\,a\,B\,b;\qquad A\,a\,B\,b'\,B\,a'\,B\,b;\qquad A\,a\,B\,b'\,a\,A'\,a\,B\,b;$$

all which will emerge parallel. Besides these there are infinite others, formed by a greater number of reflexions, and by the portions $A\,a'\,A'\,a$ of the incident beam reflected within the first glass; but these are all too faint materially to affect the image in question, which therefore we may regard as composed solely of the four rays just enumerated. Now if we cast our eye on the figure, (138,) we see the course pursued by each of these portions 1, 2, 3, 4; and it is evident that the first portion has traversed the thickness twice, and the interval between the glasses three times, or nearly; neglecting at present all consideration of the inclination of the plates $2\,t + 3\,i$. In like manner, the portion 2 will have traversed $4\,t + 3\,i$; the portion 3, $4\,t + 3\,i$; and the portion 4, $6\,t + 3\,i$. Hence it appears that the portions 1 and 4 differ in their routes by nearly four times the thickness of the glass, and can therefore produce no colours; but the other portions, at a perpendicular incidence, would not differ at all, and at very small inclinations of the plates, and of the incident ray, will only differ by reason of the small differences of the inclinations at which they traverse their respective thicknesses and intervals. They will, therefore, interfere so as to produce colour; and this will be dependent on the interval of retardation of one ray behind the other, arising from the varying obliquity of the ray which enters the eye. Fig. 138.

Now when we look at a luminous image of sensible magnitude, the rays by which we see its several points 692.

Isochromatic Lines defined.

are incident in all planes, and at all inclinations. Hence, the image seen will appear of different colours in its different points, and the disposition of these colours will follow the law, whatever it be, which regulates the interval of retardation. The colours, therefore, will be arranged in bands, circles, or other forms, according to the form of the curves arising geometrically from the consideration of equal intervals of retardation prevailing in every point of their course. Such curves, now and hereafter, we shall term *isochromatic lines*, or lines of equal tint, measuring in all cases the *tint* numerically by the number of undulations, or parts of an undulation of mean yellow light to which the interval of retardation is equal.

693. Fig. 139. Let us, then, first consider the case when the ray is incident in a plane perpendicular to the common section. In this case, fig. 139, let K L M N be a ray formed by the union of two rays S A a B b I K L and S C E F G H K L, whose courses through the system are similar to 2 and 3, fig. 138. Draw A D perpendicular to S C, then will the interval of retardation be equal to

$$\{DC + CE + EF + FG + GH + HK\} - \{Aa + aB + Bb + bI + IK\}$$
$$= DC + (EF - aB) + (FG - IK) + 2(KH - Bb),$$

the first three terms being performed in air, the last in glass. Now, without entering into a trigonometrical calculation, it is evident that this will be very small at a perpendicular incidence, and will increase rapidly as the angle of incidence varies; and that (the inclination of the plates remaining constant) it will increase by nearly equal increments, as the incidence varies by equal changes from 0 on either side of the perpendicular. Therefore, in a direction at right angles to the common section of the surfaces the tints will vary rapidly, increasing on either side of the perpendicular incidence; and at very moderate obliquities on either side, the interval of retardation will become too great for the production of colour. On the other hand, if we conceive the rays S A, S C, to be incident in a plane very nearly parallel to the principal section, then will the points K and G be situated, not, as in the figure, at different distances from P, but at very nearly the same; so that (whatever be the incidence) K I will very nearly equal G F, and for the same reason F E will very nearly equal a B. Moreover, in this case G K will be very nearly equal to F I, and the angles of internal incidence will be also very nearly equal, so that H G + G K will differ very little from B b + b I, and I B will be very nearly equal to G K, and therefore to I F, so that the point F will almost exactly coincide with B, and the rays S A a B, S C E F will coincide almost precisely, making D C = 0; and these approximate equalities and coincidences will continue for great variations in the *angle* of incidence, provided the *plane* of incidence be unaltered. The interval of retardation, then, will in this case depend very little on the angle of incidence; so that in a direction parallel to the common section of the surfaces, the tints will vary but little. Hence it appears that they will be arranged in the manner described by Dr. Brewster, *viz.* in fringes parallel to that line. Their general analytical expression is, however, rather too complex to be here set down, though very easily investigated from what has been said.

694. Fig. 140. By intercepting the principal transmitted beam in the direct image, and receiving on the eye only those portions of the rays going to form it whose curves are as in fig. 140, or the portions A a' A$'$ a B b, and A a B b' B$'$ b, Dr. Brewster succeeded in rendering visible a set of coloured fringes, which in general are diluted and concealed in the overpowering light of the direct beam. They originate evidently in the interference of these two rays, whose courses are each represented by $4t + i$, and would therefore be strictly equal were the plates exactly parallel. Their theory, after what has been said, will be obvious on inspection of the figure, as well as those of all the rest of the systems of fringes which he has described in that highly curious and interesting memoir.

695 Fringes between glass films. Mr. Talbot has observed, when viewing films of blown glass in homogeneous yellow light, and even in common daylight, that when two films are superposed on each other, bright and dark stripes, or coloured bands and fringes of irregular forms, are produced between them, though presented by neither separately. These are obviously referable to the same principle, the interference taking place here between rays respectively twice reflected within the upper lamina, and once reflected at the upper surface of the lower lamina, or else between rays one of which is thrice reflected in the mode represented by A a B$'$ a' B$'$ a A, and the other in that represented by A a B$'$ a A$'$ a' A, the interval between the glasses being supposed to be exactly equal to the thickness of the upper one in both cases, a condition which is sure to obtain somewhere when the laminæ are curved. A still more curious and delicate case of the production of similar fringes has been noticed by Professor Amici, to take place when two of the blue feathers of the wing of the *Papilio Idas* (a species of butterfly) are laid on each other in the field of his powerful and exquisite microscopes. These feathers he describes as small plates of perfect transparency, and uniformly and delicately striated over their whole surface. The fringes in question are formed between them, and vary in breadth, form, and situation, according to the manner in which the feathers are superposed. Their origin seems to be independent of the striæ however, and is easily understood on the principles above explained. The same may be said of the colours observed by Mr. Nicholson in combinations of parallel glasses of unequal thickness. Suppose, for instance, that instead of the plates having exactly equal thicknesses, their thicknesses t, t' differ by a very minute quantity, then the course of the rays A a' A$'$ a B b and A a B b' B$'$ b will (at a perpendicular incidence) be respectively $3t + i + t'$ and $t + i + 3t'$, (supposing the plates strictly parallel,) and the difference of their routes is $2t - 2t'$; so that if this be exceedingly minute, colours will arise, or, if not, may be produced by a slight inclination of the plates to each other, and so of an infinite variety of cases which may arise.

§ VI. *Of the Colours of Mixed Plates.*

696. Interference of rays not strictly coincident.

The colours hitherto described have been referred to the interference of rays rigorously coincident with each other throughout their whole course, after the point where they begin to be superimposed. Such interfering rays, or systems of waves, being united into a point on the retina, that point is agitated by the sum or difference of their actions, and the sensation produced is according. But if this coincidence be only approximate, as, if two systems of waves be propagated from origins so nearly coincident in angular situation from the eye, that their images formed on the retina shall be too close to be distinguished by the mind from the image of a single point, the impressions produced will still be confounded together; or rather, we ought to say, the mechanical action on one point will be propagated through the substance of the retina to the other, and a sensation corresponding to their mean or average effect will be produced. If, then, the rays concentered on contiguous points of the retina be in exact discordance, and of equal intensity, a mutual destruction will take place, as if they fell on one mathematical point; if in exact accordance, they will increase each others effects, and so for the intermediate states.

697. Irradiation.

To apprehend this more fully, we must consider that the impression of light appears to spread on the retina to a certain extremely minute distance all around the mathematical focus of the rays concentered by the lenses of the eye. Thus the image of a star is never seen as a *point*, but as a disc of sensible size, and that the larger as the light is stronger. Thus, too, the bright part of the new moon is seen, as it were, larger than the faintly illuminated portion of its disc projecting beyond it as an acorn cup beyond the fruit, &c. This effect is termed *irradiation*, and is manifestly the consequence of an organic action such as we have described.

698.

It follows from this, that when waves emanate from origins *undistinguishably near*, they may be regarded in their effects on the eye as emanating from origins strictly in one and the same right lines, the direction of the joint ray; and the laws of their interferences will be precisely the same, considered in their effect on vision, as if the lenses of the eye were away, and the retina were a mere screen of white paper, on a single physical point of which (*viz.* the point where the images concentered by the lenses *would* have fallen) the interfering undulations propagated simultaneously from the two origins fell, and agitated it with a vibration equal to their resultant.

699. Phenomena of mixed plates.

This premised, we are in a condition to appreciate the explanation afforded by the undulatory doctrine of the phenomena of mixed plates. They were first noticed (says Dr. Young) by him "in looking at a candle through two pieces of plate glass with a little moisture between them. He thus observed an appearance of fringes resembling the common colours of thin plates; and upon looking for the fringes by reflexion, found that the new fringes were always in the same direction as the others, but many times larger. By examining the glasses with a magnifier, he perceived, that wherever the fringes were visible, the moisture was intermixed with portions of air producing an appearance similar to dew." "It was easy to find two portions of light sufficient for the production of these fringes; for the light transmitted through the water moving in it with a velocity different from that of light passing through the interstices filled only with air, the two portions would interfere with each other and produce effects of colour according to the general law. The ratio of the velocities in water and air is that of three to four; the fringes ought therefore to appear where the thickness is six times as great as that which corresponds to the same colour in the common case of thin plates; and upon making the experiment with a plane glass and a lens slightly convex, he found the sixth dark circle actually of the same diameter as the first in the new fringes. The colours are also easily produced when butter or tallow is substituted for water, and the rings then become smaller in consequence of the greater refractive density of the oils; but when water is added so as to fill up the interstices of the oil, the rings are very much enlarged; for here the difference of velocities in water and in oil is to be considered, and this is much smaller than the difference between air and water. All these circumstances are sufficient to satisfy us of the truth of the explanation, and is still more confirmed by the effect of inclining the plates to the direction of the light; for then, instead of dilating like the colours of thin plates, these rings contract, and this is the obvious consequence of an increase of the lengths of the paths of the light which now traverses both media obliquely, and the effect is everywhere the same as that of a thicker plate. It must, however, be observed, that the colours are not produced in the whole light that is transmitted through the media; a small portion only of each pencil passing through the water contiguous to the edges of the particle is sufficiently coincident with the light transmitted through the neighbouring portions of air to produce the necessary interference; and it is easy to show that a considerable portion of the light that is beginning to pass through the water will be dissipated laterally by reflexion at its entrance, on account of the natural concavity of the surface of each portion of the fluid adhering to the two surfaces of the glass, and that much of the light passing through the air will be scattered by refraction at the second surface. For these reasons the fringes are seen when the plates are not directly interposed between the eye and the luminous object." (Young, *Phil. Trans.* 1802; *Account of some Cases of the Production of Colours.*) To see the phenomena to advantage, we may add, it is only necessary to rub up a little froth of soap and water almost dry between two plane glasses, and hold them at a distance from the eye between it and a candle, or the reflexion of the sun on any polished convex object. If two slightly convex glasses, or a plane and a convex one be used, the colours are seen arranged in rings.

§ VII. *Of the Colours of Fine Fibres and Striated Surfaces.*

700. Interference of rays reflected from points or lines very near each other. Fig. 141.

If two points supposed capable of reflecting light in all directions (as two infinitely small spheres, &c.) be so near each other as to appear to the eye as one, and if rays from a common origin reflected from them reach the eye, they will interfere; and if the light be homogeneous, its intensity will vary periodically, with an interval of retardation corresponding to the difference of their paths; if white, the colour of the mixed reflected ray will be the same as if it had been transmitted through a plate of air of a thickness equal to that difference, but deprived of its diluting white. Suppose two exceedingly fine cylindrical polished fibres to be placed at right angles to the line of sight, and parallel to each other, as in fig. 141, as A B C, *a b c*; and let S be a luminous point very distant with respect to the interval of the fibres, and E the eye, placed so as to receive the reflected rays B E, *b* E, which, by supposition, are near enough to interfere. Then the differences of phases of the rays on the retina is evidently equal to $2\pi \times \frac{(\mathrm{S}b + b\mathrm{E}) - (\mathrm{SB} + \mathrm{BE})}{\lambda} = 2\pi . \frac{bx + by}{\lambda}$, supposing B x and B y perpendicular to S *b* and *b* E. If, then, we suppose I and *i* to be the angles of incidence of the rays S B, E B on the plane in which the axes of the two cylinders A C, *a c* lie, and put B *b* their distance equal to *a*, we have for the difference of phases

$$2\pi . \frac{a}{\lambda} . (\sin \mathrm{I} + \sin i).$$

Hence, if *a* remain the same, this will vary with the obliquity both of the incident and reflected ray to the plane of the axes of the fibres; and, therefore, if that plane be turned about an axis parallel to the fibres, a succession of colours analogous to the transmitted series of those of their plates, but much more vivid, will be seen, as if reflected on them.

701. Colours of scratches on striæ.

Any extremely fine scratch on a well polished surface may be regarded as having a concave, cylindrical, or, at least, a curved surface capable of reflecting the light equally in all directions; this is evident, for it is visible in all directions. Two such scratches, then, drawn parallel to each other, and then turned round an axis parallel to both in the sunshine, ought to affect the eye in succession with a series of colours analogous to those of thin plates. This is really the case. Dr. Young found, on examining the lines drawn on glass in Mr. Coventry's micrometric scales, each of them to consist of two or more finer lines exactly parallel, and at a distance of about one 10,000th of an inch. Placing the scale so as to reflect the sun's light at a constant angle, and varying the inclination of the eye, he found the brightest red to be produced at angles whose sines were in the arithmetical progression 1, 2, 3, 4.

702. Of systems of equidistant parallel lines.

In the beautiful specimens of graduation on glass and steel produced by Dr. Wollaston, Mr. Barton, and M. Fraunhofer, single lines exactly parallel to each other, and distant in some cases not more than one 10,000th of an inch, and at precisely equal intervals, are drawn with a diamond point. If the eye be applied close to a reflecting or refracting surface so striated, so as to view a distant, small, bright light reflected in it, it will be seen accompanied with splendid lateral spectra, which evidently originate in this manner. They are arranged in a straight line passing through the reflected, colourless image, and at right angles to the direction of the striæ. Their angular distances from each other, the succession of their colours, and all their other phenomena, are in perfect agreement with the above explanation. Their vividness depends on the exact equality of distance between the parallel lines, which causes the lateral images produced by each pair to coincide precisely in distance from the principal image, and thus to produce a multiplied effect. If the distance of the lines be unequal, the images from different pairs, not coinciding, blend their colours, and produce a streak, or ray of white light. This is the origin of the rays seen darting, as it were, from luminous objects reflected on irregularly polished surfaces. These colours may be transferred, by impression from the surface originally graduated, to sealing wax, or other soft body; or from steel, by violent pressure, to softer metals. It is in this way that those beautiful striated buttons and other ornaments are produced, which imitate the splendour and play of colours of the diamond.

703. Alleged analogy between colours of striated surfaces and certain musical tones considered.

Dr. Young has assimilated the colour thus produced when a beam of white light strikes on a succession of parallel equidistant lines, to the musical tone heard when any sudden sound is *echoed* in succession by a series of equidistant bars having flat surfaces situated in a direction perpendicular to the line in which they are arranged, for instance, an iron railing. It is evident that such echoes will reach the ear in succession, at precisely equal intervals of time, each being equal to the time taken by sound to traverse twice the space separating the bars; and thus producing on the ear, if the bars be sufficiently numerous, the effect of a musical sound. (*Phil. Trans.* 1801; *On the Theory of Light and Colours.*) This explanation, however, appears to us, we confess, more ingenious than satisfactory. The pitch of the musical tone produced by the echoes is independent of the sound echoed, which may be a single blow, or a *noise*, (*i. e.* a sound consisting of non-periodic vibrations,) and requires for its production a number of echoing bars sufficient to prolong the echoes a sensible time. On the other hand, the light reflected from parallel striæ depends for its colour wholly on the incident ray, being red in red light, yellow in yellow, &c.; and is produced equally well from two or from twenty, as from a million of such reflecting lines. The intensity, not the colour,—the magnitude, not the frequency of the impression made on the retina by the reflected rays, is modified by their interference. We think it necessary to point out this defect in the illustration in question, inasmuch as it has become popular for its ingenuity, and *primâ facie* plausibility; while, in reality, it is calculated to give very erroneous impressions of the analogy between sound and light.

704. Colours of a spider's web, &c. A single scratch or furrow in a surface may, as that eminent philosopher has himself remarked, produce colours by the interference of the rays reflected from its opposite edges. A spider's thread is often seen to gleam in the sunshine with the most vivid colours. These may arise either from a similar cause, or from the thread itself as spun by the animal, consisting of several, agglutinated together, and thus presenting not a cylindrical, but a furrowed surface.

705. Of mother of pearl. The phenomena exhibited by light reflected from and refracted through the polished surface of mother of pearl, are, no doubt, referable in great measure to the same principle, so far as they depend on the structure of the surface. Dr. Brewster has described them in a most curious and interesting Paper, (published in the *Phil. Trans.* 1814, p. 397;) and a writer in the *Edinburgh Philosophical Journal*, vol. ii. p. 117, has added some further particulars illustrative of the curious and artificial structure of this singular body. Every one knows that mother of pearl is the internal lining of the shell of a species of oyster. It is composed of extremely thin laminæ of a tough and elastic, yet at the same time hard and shelly substance, disposed parallel to the irregular concavity of the interior of the shell. When, therefore, any portion of it is ground and polished on a plane tool, the artificial surface so produced intersects the natural surfaces of the laminæ in a series of undulating curves, or level-lines, which are nearer or farther asunder, according to the varying obliquity of the artificial to the natural surfaces. As these laminæ adhere imperfectly to each other, their *feather-edges* become broken up by the action of the powders, &c. used in grinding and polishing them, so as to present a series of ridges or escarpments arranged (when any very small portion of the surface only is considered) nearly parallel to, and equidistant from each other, which are distinctly seen with a microscope, and which no polishing in the least degree obliterates or impairs. The light reflected, therefore, or dispersed on their edges, will interfere and produce coloured appearances in a direction perpendicular to that of the striæ. This is, in fact, their situation; but the phenomena are modified in a very singular manner by the peculiar form of the edges and hollows, which results, no doubt, from the crystalline structure of the pearl. That it is the configuration *only* of the surface on which they depend, is evident from the remarkable fact, that, like the colours described in Art. 702, they may be transferred, by impression, to sealing wax, gum, resin, or even metals, with little or no diminution of their brilliancy; and the impression so transferred, if examined by the microscope, is found to exhibit a faithful copy of the original striæ, though sometimes so minute as hardly to exceed one 3000th of an inch in their distance from each other. For a particular description of this very curious and beautiful class of phenomena, however, our limits oblige us to refer to the original memoirs already cited, especially as their theory is still accompanied with some obscurity.

§ VIII. *Of the Diffraction of Light.*

706. Fringes formed exterior to the shadows of bodies in a small beam of light. When an object is placed in a very small beam of light, or in the cone of rays diverging from an extremely small point, such as a sunbeam admitted through a small pin-hole into a dark chamber, or, still better, through an opening of greater size, behind which a lens of short focus is placed, so as to form an extremely minute and brilliant image of the sun from which the rays diverge in all directions, its shadow is observed to be bordered externally by a series of coloured fringes which are more distinct the smaller the angular diameter of the luminous point, as seen from the object. If this be much increased, the shadow and fringes formed by its several points, regarded each as an independent luminary, overlap and confuse each other, obliterating the colours, and producing what is called the *penumbra* of the object; but when the luminous point is extremely minute, the shadow is comparatively sharp, and the fringes extremely well defined.

707. Their colours, &c. described. These fringes (which were first described by Father Grimaldi in a work entitled *Physico-Mathesis de Lumine*, Bologna, 1665, and afterwards more minutely by Newton in the third book of his *Optics*) surround the shadows of objects of all figures, preserving the same distance from every part, like the lines along the sea-coast in a map; only, where the object forms an acute, salient angle, the fringes curve round it; and where it makes a sharp, reentering one they cross, and are carried up to the shadow at each side, without interfering or obliterating each other. In white light three only are to be seen, whose colours, reckoning from the shadow, are black, violet, deep blue, light blue, green, yellow, red; blue, yellow, red; pale blue, pale yellow, pale red. In homogeneous light they are, however, more numerous, and of different breadths, according to the colours of the light, being narrowest in violet and broadest in red light, as in the coloured rings between glasses; and it is by the mutual superposition of the different sets of fringes for all the coloured rays that their tints are produced, and their obliteration after a few of the first orders caused.

708. Are independent of the body casting the shadow. The fringes in question are absolutely independent of the nature of the body whose shadow they surround, and the form of its edge. Neither the density or rarity of the one, nor the sharpness or curvature of the other, having the least influence on their breadth, their colours, or their distance from the shadow; thus it is indifferent whether they are formed by the edge or back of a razor, by a mass of platina or by a bubble in a plate of glass, (which, though transparent, yet throws a shadow by dispersing away the light incident on it,) circumstances which make it clear that their origin has no connection with the ordinary refractive powers of bodies, or with any *elective* attraction or repulsions exerted by them on light; for such forces cannot be conceived as independent of the *density* of the body exerting them, however minute we might regard the sphere of their action.

709. M. Fresnel's method of examining them. To see the fringes in question, they may be received on a smooth, white surface, and examined and measured thereon by contrivances which readily occur; this was the mode pursued by Newton. M. Fresnel, however, having (to avoid the inconvenience of intercepting the light by the interposition of the observer) received them on an emeried glass plate, was enabled, by placing himself behind it, to approach near enough to examine and measure

them with a magnifier. In so doing, however, he observed, that when thus once brought under inspection, they continued visible, and were indeed much brighter and more distinct in the focus of the lens (as if depicted in the air) even when the emeried glass was altogether withdrawn; and this fortunate observation, by enabling him to avoid the use of a screen altogether, and to perform all his measurements of their dimensions by the aid of a micrometer, put it in his power to examine them with a degree of minuteness and precision no other way attainable, and fully adequate to the delicacy of the inquiry: for it is manifest that the fringes, being seen as they would be formed if received on a screen in the focus, may be regarded as any other optical image formed in the focus of a telescope, viewed with any magnifier, and treated in all respects as such images.

710. Their phenomena.

Whatever mode of examining them we adopt, however, we shall observe the following facts:

1st. Their distances, *inter se.*

Phenomenon 1. That, *cæteris paribus*, the distances from each other and from the border of the shadow diminishes as the screen on which they are received, or the plane in the focus of the lens in which they are formed, approaches the border of the opaque body, and ultimately coincides with it, so that they seem to have their origin close to the edge of the body.

711. They are propagated in curved lines.

Phenomenon 2. That they are not, however, *propagated in straight lines* from the edge of that body to a distance, but in hyperbolic curves, having their vertices at that edge; and therefore that it is not *one and the same* light which forms one and the same fringe at all distances from the opaque body. To explain this, conceive the distances of the fringes from each other and from the shadow measured accurately at a great variety of distances from the edge of the body; then, were they propagated in straight lines, and were each fringe really the axis of a pencil of rays emanating from a point at that edge, their intervals and distances from the shadow ought to be proportional to the distances from the edge of the body; but it is not so, in fact,—the former distances increasing as we recede from the opaque body much more rapidly at first, and less so as we recede, than according to the law of proportionality; and if the *locus* of each fringe be laid down from such measures, it will be found to be an hyperbolic curve having its convexity outwards or from the shadow. Thus in fig. 142 O is the luminous point, A the edge of the body, and G H a screen perpendicular to the straight line O A, C the border of the visible shadow, and D, E, F the places of the successive minima of the fringes in a line at right angles to the edge of the shadow. If the screen be brought nearer to the body A as at *g h*, and if *c*, *d*, *e*, *f* be the points corresponding to C D E F, their loci will be the hyperbolas A*c*C, A*d*D, &c. (Fig. 142.)

712. The visible shadow differs from the geometrical one and is larger.

It will be noticed also that the border C of the visible shadow is not coincident with B, that of the *geometrical* one, which lies in the straight line O A, grazing the edge of the object. The deviation is difficult to perceive in the shadow of a large body, having nothing to measure from; but if we examine those of very narrow bodies, as of a hair, for instance, in such a beam of light as described, we shall find on measuring the total breadth of the shadow a full proof of this. This fact was observed by Grimaldi. The limit of the visible shadow also follows the same law of curvilinear propagation as the fringes. Thus, Newton found the shadow of a hair one 280th of an inch in diameter placed at 12 feet distance from the luminous point, to measure at 4 inches from the hair $\frac{1}{60}$ inch, or upwards of 4 diameters of the hair, at two feet, $\frac{1}{28}$ inch, or 10 diameters; while at 10 feet it measured only $\frac{1}{8}$ inch, or 35 diameters, instead of 120, which it should have done if the rays terminating the shadow had proceeded in straight lines; or rather, to speak more correctly, if the shadow were bounded by straight lines.

713. Newton's doctrine of the deflexion of light. Fig. 143.

To account for these remarkable facts, Newton supposes that the rays passing at different distances from the edges of bodies are turned aside outwards, *as if* by a repulsive force; and that those nearest are turned more aside than those more remote, as in fig. 143, where X is a section of the hair, and A D, B E, C F, &c. rays which pass at different distances beside it, and which are turned off at angles rapidly diminishing as the distance increases in directions D G, E H, F I, &c. It is manifest that the curve W Y Z, to which all these deflected rays are tangents, and within which none can enter, will be convex outwards; and its curvature will be greatest at the vertex W, and will diminish continually as it recedes from X, being, in fact, the caustic of all the deflected rays.

714. His account of the fringes. Fig. 144.

This will be the boundary of the visible shadow. To account for the fringes, he supposes (*Optics*, book iii. question 3) that each ray in its passage by the body undergoes several flexures to and fro, as in fig. 144 at *a*, *b*, *c*; and that the luminous molecules, of which that ray consists, are thrown off at one or other of the points of contrary flexure, or other determinate points of the serpentine curve described by them according to the state of their fits in which they there happen to be, or other circumstances; some outwards, as in the directions *a*A, *b*B, *c*C, *d*D, and others we may suppose inwards, as $a\,\alpha$, $b\,\beta$, $c\,\gamma$, &c. With the latter we have here no concern. The former, it is evident, will give rise to as many such caustics as above described, as there are deflected rays; and each caustic, when intercepted on a screen at a distance, will depict on it the maximum of a fringe. The intervals, however, between these caustics, or minima of the fringes, will not be totally black; because the rays from the other caustics, after crossing on the confines of the shadow, or interior fringes, will pursue their course, and partially illuminate all the space beyond. Thus the fringes should be less numerous and the degradation of colour more rapid than in the coloured rings.

715. Newton's doctrine and Fresnel's objections to it considered.

This theory accounts then perfectly for the curvilinear propagation of the fringes, for their rapid degradation, for their apparently originating in the very edge of the body, (since each caustic will actually come up to that edge, as at A, fig. 142,) and for the remarkable brightness of the fringes, especially the first, which really contains in itself all the light which would have passed into the region B C between the visible and geometrical shadows. It should appear, therefore, that M. Fresnel, in the objections he has taken against these points of the Newtonian doctrine of inflexion in his excellent work *Sur la Diffraction de la Lumière*, (§ 1, p. 15, 17, 19,) must have formed a very inadequate conception of the doctrine he opposes, which, if viewed in the light he has there placed it in, would indeed deserve no other epithet than puerile, and must be looked upon as quite unworthy of its illustrious author; and were these the only difficulties to be explained, we should certainly not be justified in passing a hasty sentence on it. Other objections advanced by the same eminent philosopher, however, are more serious, and refer to a phenomenon of which the doctrine of deflective forces seems incapable of giving any account; but of which, in justice to Newton we ought to add, it does not appear that he was aware, or its importance could not fail to have struck him.

716. Dilatation of the fringes by the approach of the radiant point.

Phenomenon 3. All other things remaining the same, let the opaque body A be brought nearer the luminous point O, (fig. 142.) The fringes then, formed at the same distance as before behind A, are observed to dilate considerably in breadth,—preserving, however, the same relative distances from each other, and from the border of the shadow. This fact is evidently incompatible with the idea of their being caused by any deflecting force emanating from the opaque body, since it is inconceivable that such a force should depend on the distance the light has travelled from another point no way related to the body.

717. Dr. Young's explanation of the fringes on the undulatory doctrine. Objections against it.

To explain the diffracted fringes on the undulatory doctrine, Dr. Young conceived the rays passing near the edge of the opaque body to interfere with those reflected very obliquely *on* its edge, and which in the act of reflexion had lost half an undulation, as in the case of the reflected rings. This supposition would, in fact, lead us to conclude the existence of a series of fringes propagated hyperbolically, and perfectly resembling those really existing. M. Fresnel, however, has shown that a minute though decided difference exists between their places, as given by this theory and by direct measurement; and has, moreover, remarked, that were this the true explanation, they could hardly be supposed absolutely independent of the figure of the edge of the opaque body, which experience shows they are; and that in cases where this edge is extremely sharp, the small quantity of light which *could* be reflected from it would be insufficient to interfere with that passing by it, so as to form fringes so bright as we see them. These objections appear conclusive, especially as the supposition of a reflexion on the edge of the body is unnecessary, since a more strict application of the undulatory doctrine, assisted by the principle of interferences, will be found to afford a full and precise explanation of all the facts, regarding the opaque body as merely an obstacle *bounding* the waves propagated from the luminous point on one side.

718. Fresnel's explanation Fig. 145.

To show this, let us consider a wave A M F propagated from O, and of which all that part to the right of A (fig. 145) is intercepted by the opaque body A G; and let us consider a point P in a screen at the distance A B behind A, as illuminated by the undulations emanating simultaneously from every point of the portion A M F, according to the theory laid down in Art. 628, *et seq.* For simplicity, let us consider only the propagation of undulations in one plane. Put $AO = a$, $AB = b$, and suppose $\lambda =$ the length of an undulation; and drawing P N any line from P to a point near M, put $PF = f$, $NM = s$, $PB = x$; then, supposing P very near to B, and with centre P radius P M describing the circle Q M, we shall have $f = PQ + QN = \sqrt{(a+b)^2 + x^2} - a + QN = b + \frac{x^2}{2(a+b)} + QN$. Now, Q N is the sum of the versed sines of the arc s to radii O M and P M, and is therefore equal to $\frac{s^2}{2\,OM} + \frac{s^2}{2\,PM} = \frac{s^2}{2}\left(\frac{1}{a} + \frac{1}{b}\right) = \frac{a+b}{2ab} \cdot s^2$; so that, finally,

$$f = b + \frac{x^2}{2(a+b)} + \frac{(a+b)\,s^2}{2ab}.$$

Now, if we recur to the general expression demonstrated in Art. 632, for the motion propagated to P from any limited portion of a wave, we shall have in this case $a \cdot \phi(\theta) = 1$, because we may regard the obliquity of all the undulations from the whole of the efficacious part of the surface A M N as very trifling, when P is very distant from A in comparison with the length of an undulation. And as we are now only considering undulations propagated in one plane, that expression becomes merely $V = \int ds \cdot \sin 2\pi\left(\frac{t}{T} - \frac{f}{\lambda}\right)$, and the corresponding expression for the excursions of a vibrating molecule at P will be

$$X = \int ds \cdot \cos 2\pi\left(\frac{t}{T} - \frac{f}{\lambda}\right).$$

If then we put for f its value, and take

$$2\pi\left(\frac{t}{T} - \frac{b}{\lambda} - \frac{x^2}{2\lambda(a+b)}\right) = \theta; \qquad s \cdot \sqrt{\frac{2(a+b)}{ab\lambda}} = \nu,$$

and consider that in those expressions t and x remain constant, while s only varies, the latter will take the form

$$X = \sqrt{\frac{ab\lambda}{2(a+b)}} \cdot \left\{\cos\theta \cdot \int d\nu \cdot \cos\left(\frac{\pi}{2}\nu^2\right) + \sin\theta \cdot \int d\nu \cdot \sin\left(\frac{\pi}{2}\nu^2\right)\right\},$$

which shows that the total wave on arriving at P may be regarded as the resultant of two waves $X' \cdot \cos\theta$ and $X'' \cdot \sin\theta$, differing in their origin by a quarter-undulation, and whose amplitudes X' and X'' are given by the expression

$$X' = \sqrt{\frac{ab\lambda}{2(a+b)}} \cdot \int d\nu \cos\frac{\pi}{2}\nu^2; \qquad X'' = \sqrt{\frac{ab\lambda}{2(a+b)}} \cdot \int d\nu \cdot \sin\frac{\pi}{2}\nu^2,$$

the integrals being taken between limits of ν corresponding to $s = -AM$, and $s = +\infty$. Consequently, since

$$s = \mathrm{AM} = \mathrm{PB} \times \frac{a}{a+b} = \frac{a\,x}{a+b}, \text{ and } \nu = s\sqrt{\frac{2\,(a+b)}{a\,b\,\lambda}},$$

the limits of ν must be

$$\nu = -x\sqrt{\frac{2\,a}{(a+b)\,b\,\lambda}} \text{ and } \nu = +\infty.$$

719. Rule for determining the illumination of any point in the screen.

Hence, to determine the intensity of the light at any point P on the screen, we must first of all calculate the values of these integrals; and having thus determined X' and X'', the square root of the sum of their squares $\sqrt{X'^2 + X''^2}$ will represent the amplitude of a single vibration, the resultant of both, (Art. 615;) and the sum of their squares simply $(X'^2 + X''^2)$, the intensity of the light, or the sensation produced in the eye.

720. Maxima and minima numerically estimated.

M. Fresnel, in the work already cited, has given a table of the values of these integrals for limits successively increasing from 0 up to ∞, (at which latter limit each is equal to $\frac{1}{2}$, as may readily be proved;) and, calculating on this, he finds that the intensity of the light, without the limit of the geometrical shadow, passes through a series of maxima and minima according to the following table:

Table of the Maxima and Minima for the Exterior Fringes, and of the Corresponding Intensities of the Light illuminating them.

	Values of ν.	Intensities of the light.		Values of ν.	Intensities of the light.
First maximum	1.2172	2.7413	Fourth minimum ..	3.9372	1.7783
First minimum	1.8726	1.5570	Fifth maximum	4.1832	2.2206
Second maximum ..	2.3449	2.3990	Fifth minimum	4.4160	1.8014
Second minimum ..	2.7392	1.6867	Sixth maximum	4.6069	2.1985
Third maximum ..	3.0820	2.3022	Sixth minimum	4.8479	1.8185
Third minimum	3.3913	1.7440	Seventh maximum..	5.0500	2.1818
Fourth maximum ..	3.6742	2.2523	Seventh minimum ..	5.2442	1.8317

In this it is to be remarked, that no minimum is zero, and that the difference between the successive maxima and minima diminishes very rapidly as the values of ν increase, which explains the rapid degradation of their tints.

721. Illumination of the border of the geometrical shadow.

If the point P be situated on the very edge of the geometrical shadow, its illumination should on this theory be $(\frac{1}{2})^2 + (\frac{1}{2})^2 = \frac{1}{2}$. To compare this with the illumination of the same point, were the opaque body removed, we have only to consider, that at a great distance from the shadow the light must be the same, whether the body be there or not. Now the limit to which the maxima and minima approximate is 2, which therefore represents the uniform illumination beyond the fringes; so that the light on the border of the geometrical shadow is equal to $\frac{1}{4}$ of the full illumination from the radiant point.

722. Illumination within the shadow.

Within the shadow we have only to make s or ν negative. This does not alter the values of the integrals, but it does their limits, which must in that case be taken not from $\nu = -x\sqrt{\frac{2\,a}{(a+b)\,b\,\lambda}}$ to $+\infty$, but from $\nu = +x\sqrt{\frac{2\,a}{(a+b)\,b\,\lambda}}$ to $+\infty$. The computations have been executed by M. Fresnel, who finds that no periodical increase or decrease here takes place, but that the light degrades rapidly and constantly within the geometrical shadow to total darkness.

723. Visible shadow larger than the geometrical.

The actual visible shadow then is marked by no sudden defalcation of light, and it will depend on the judgment of the eye where to establish its termination. If we regard all that part as shadow which is less illuminated than the general light of the screen beyond the fringes, then the visible shadow will extend considerably beyond the geometrical one, and this explains why the shadows of small bodies are so much dilated, as we have seen they are.

724. If we would know the breadths of the several fringes, we have only to find the values of x in the equation

$$x = \nu \,.\, \sqrt{\frac{(a+b)\,b}{a}\,\frac{\lambda}{2}}$$

where ν has in succession the several values set down in the foregoing table. If we consider the variation of x for successive values of a and b, we shall see the origin both of the curvilinear propagation of the fringes, and of their dilatation on the approach of the luminous point. In fact if we regard, first, the relation between b and x, or the locus of any fringe regarded as a curve, having the line A B for an abscissa and B P as an ordinate, we have $x^2 = \nu^2\,\frac{\lambda}{2}\left(b + \frac{b^2}{a}\right)$, which is the equation of an hyperbola having its convexity outwards and passing through A. Secondly, on the other hand, if we regard a as the variable quantity and b as constant, we see that for one and the same distance from the screen, the breadths of the fringes increase as a diminishes; the increments of their squares, as the incident rays from being parallel become more divergent, being directly as their divergence. Thirdly, for equal values of λ, a, and b, x is proportional to ν; so that the breadths of the several fringes are always in the same ratio to each other, and form a progression the same with those of the values of ν in the foregoing table. Lastly, the breadths of the fringes for different coloured rays are as the square roots of the lengths of their undulations.

725. The accordance of this theory with experiment, so far as it regards the distances of the fringes from the shadow and from each other, has been put to a severe test by M. Fresnel, and found perfect. It were to be wished, however, that he had stated somewhat more precisely the instrumental means by which he determined the place of the border of the *geometrical shadow*, from which his measures are all stated to be taken; and which, being marked by no phenomenon of maximum or minimum, might be liable to uncertainty if judged of by the eye alone. This, however, in no way invalidates the accuracy of the final conclusions, as the intervals between the fringes are distinctly marked, and susceptible of exact measurement. The dilatation of the fringes on the approach of the luminous point is, perhaps, the strongest fact in favour of the undulatory doctrine, and in opposition to that of inflection, which has yet been adduced. It seems hardly reconcilable to any received ideas of the action of corpuscular forces, to suppose the force of deflection exerted by the edge of a body on a passing ray, to depend on the distance which the ray has passed over before arriving at that edge from an arbitrarily assumed origin. M. Fresnel has placed this argument in a strong light, in his work already cited.

726. Fringes observed by Grimaldi within narrow shadows.

Besides the exterior fringes above described, there are others formed in certain circumstances within the shadows of bodies which afford peculiarly apt illustrations of the principle of interferences. The first class of phenomena of this kind was noticed by Grimaldi, who found that when a long, narrow body is held in a small diverging beam of light, the shadow received on a screen at a distance will be marked in the direction of its length with alternate streaks or fringes brighter and darker than the rest. These are more or less numerous, according as the distance of the shadow from the body is smaller or greater in proportion to the breadth of the latter. To study the phenomena more minutely, Dr. Young passed a sunbeam through a hole made with a fine needle in thick paper, and brought into the diverging beam a slip of card one-thirtieth of an inch in breadth, and observed its shadow on a white screen at different distances. The shadow was divided by parallel bands, as above described, but *the central line was always white*. That these bands originated in the interference of the light passing on both sides of the card, Dr. Young demonstrated beyond all controversy, by simply intercepting the light on one side by a screen interposed between the card and the shadow, leaving the rays on the other side to pass freely, in the manner represented in fig. 146, where O is the hole, A B the card, E F its shadow, and C D the intercepting body receiving on its margin the margin of the shadow of the edge B of the body. In this arrangement all the fringes which had before existed in the shadow E F immediately disappeared, although the light inflected on the edge A was allowed to retain its course, and must have necessarily undergone any modification it was capable of receiving from the proximity of the other edge B. The same result took place when the intercepting screen was placed as at *c d before* the edge B of the body, so as to throw its own shadow on the margin B of the card.

Dr. Young's fundamental interference. Fig. 146.

727. Explanation.

Without entering minutely into the rationale of this phenomenon, which, however, the formulæ of the preceding articles enable us fully to do, by considering the illumination of any point X between E and F as arising from the whole wave *a* A B *b*, *minus* the portion A B, and which M. Fresnel has done at full length, and with great success, in his Memoir already so often cited; we shall content ourselves with showing how fringes or alternations of colour must originate in such circumstances; in fact, if we join A X, B X, the difference of routes of the waves arriving at X by the paths O A X, O B X is equal to B X − A X. It is therefore nothing in the middle of the shadow E F, which ought therefore to be illuminated by double the light deflected into the shadow at that distance by either edge, Art. 722, which will be less as the object is larger, and the shadow broader. But on either side of the middle B X − A X increases; and when it attains a value equal to half an undulation, the waves are in complete discordance, and therefore the middle bright portion will be succeeded by a dark band on either side, and these again by bright ones, and so on.

728. Grimaldi's crested fringes.

An elegant variation of this experiment of Dr. Young is afforded by a phenomenon described by Grimaldi. When a shadow is formed by an object having a rectangular termination; besides the usual external fringes there are two or three alternations of colours, beginning from the line which bisects the angle, disposed, within the shadow on each side of it, in curves which are convex towards the bisecting line, and which converge towards it as they become remote from the angular point. These fringes are the joint effect of the light spreading into the shadow from each outline of the object, and interfering as above; and that they are so, is proved by placing a screen within a few inches of the object, so as to receive only one edge of the shadow, when the whole of the fringes disappear. If, on the other hand, the rectangular point of the screen be opposed to the point of the shadow, so as barely to receive the angle of the shadow on its extremity, the fringes will remain undisturbed. (Young, Experiments and Calculations relating to Physical Optics, *Phil. Trans.*, 1803.)

729. Case of diffraction through a small circular aperture.

Such are some of the more remarkable appearances produced within and beyond the shadows of narrow bodies. Let us next consider the effect of transmitting a beam through a very narrow aperture. And the first case is when the aperture is circular. Suppose, for instance, we place a sheet of lead, having a small pin-hole pierced through it, in the diverging cone of rays from the image of the sun, formed by a lens of short focus, and in the line joining the centres of the hole and focus prolonged place a convex lens or eye-glass, behind which the eye is applied. The image of the hole will be seen through the lens as a brilliant spot, encircled by rings of colours of great vividness, which contract and dilate, and undergo a singular and beautiful alternation of tints, as the distance of the hole from the luminous point on the one hand, or on the eye-glass on the other, is changed. When the latter distance is considerable, the central spot is white, and the rings follow nearly the order of the colours of thin plates. Thus, when the diameter of the hole was about $\frac{1}{30}$th of an inch, its distance

(a) from the luminous point about 6 feet 6 inches, and its distance (b) from the eye-lens 24 inches, the series of colours was observed to be,

1st order. White; pale yellow; yellow; orange; dull red.
2d order. Violet; blue (broad and pure;) whitish; greenish yellow; fine yellow; orange red, very full and brilliant.
3rd order. Purple; indigo blue; greenish blue; pure, brilliant green; yellow green; red.
4th order. Good green, but rather sombre and bluish; bluish white; red.
5th order. Dull green; faint bluish white; faint red.
6th order. Very faint green; very faint red.
7th order. A trace of green and red.

730. Table of colours of central spot and surrounding rings.

When the eye-lens and hole are brought nearer together, the central white spot contracts into a point and vanishes, and the rings gradually close in upon it in succession, so that the centre assumes in succession the most surprisingly vivid and intense hues. Meanwhile the rings surrounding it undergo great and abrupt changes in their tints. The following were the tints observed in an experiment made some years ago, (July 12, 1819,) the distance between the eye-glass and luminous point ($a + b$) remaining constant, and the hole being gradually brought nearer to the former.

$b =$	Central Spot.	Surrounded by
24.00	White	Rings as in the foregoing Article.
18.00	White	The two first rings confused, the red of the 3rd and green of the 4th orders splendid.
13.50	Yellow	Interior rings much diluted, the 4th and 5th greens and 3rd, 4th and 5th reds the purest colours.
10.00	Very intense orange	All the rings are now much diluted.
9.25	Deep orange red	The rings all very dilute.
9.10	Brilliant blood red	The rings all very dilute.
8.75	Deep crimson red	The rings all very dilute.
8.36	Deep purple	The rings all very dilute.
8.00	Very sombre violet	A broad yellow ring.
7.75	Intense indigo blue	A pale yellow ring.
7.00	Pure deep blue	A rich yellow.
6.63	Sky blue	A ring of orange, from which it is separated by a narrow, sombre space.
6.00	Bluish white	Orange red, then a broad space of pale yellow, after which the other rings are scarcely visible.
5.85	Very pale blue	A crimson red ring.
5.50	Greenish white	Purple, beyond which yellow verging to orange.
5.00	Yellow	Blue, orange.
4.75	Orange yellow	Bright blue, orange red, pale yellow, white.
4.50	Scarlet	Pale yellow, violet, pale yellow, white.
4.00	Red	White, indigo, dull orange, white.
3.85	Blue	White, yellow, blue, dull red.
3.50	Dark blue	Orange, light blue, violet, dull orange.

731. Fresnel's analysis of this case.

The series of tints exhibited by the central spot is, evidently, so far as it goes, that of the reflected rings in the colours of thin plates. The surrounding colours are very capricious, and appear subject to no law. They depend, indeed, on very complicated and unmanageable analytical expressions, with which we shall not trouble the reader, but content ourselves with presenting the explanation given by M. Fresnel of the changes of tint of the central spot in white light, and its alternations of light and total darkness observed by him in an homogeneous illumination. Let then a and b be the distances of a small hole whose radius is r from the luminous point, and a screen placed behind the hole perpendicularly to the ray passing directly through its centre. Then if we consider any infinitely narrow annulus of the hole whose radius is z, and breadth $d\,z$, this annulus will send to the central point of the screen a system of waves whose intensity is proportional to the area of the annulus, or $2\,\pi\,z\,d\,z$, but whose phase of undulation differs from that of the central ray, by reason of the difference of the paths described by them. Now, calling f the distance of each point in the annulus from the centre of the screen, we have $f^2 = b^2 + z^2$, and, in like manner, if f' be the distance of the luminous point from the same annulus, $f'^2 = a^2 + x^2$, so that $(f + f') - (a + b)$ the difference of paths, or interval of retardation, is equal to $\frac{z^2}{2}\left(\frac{1}{a} + \frac{1}{b}\right) = \frac{z^2\,(a+b)}{2\,a\,b}$. Hence, the general expression in Art. 632 for the amplitude of the total wave, incident on the centre of the screen in this particular case, is equivalent to

$$X = \int 2\,\pi\,z\,d\,z\,.\,\sin 2\,\pi \left\{\frac{t}{T} - \frac{z^2\,(a+b)}{2\,a\,b\,\lambda}\right\},$$

or, integrating, which from the peculiar form of the differential is in this case easy,

$$\mathrm{X} = \frac{a\,b\,\lambda}{a+b}\left\{\text{const} + \cos 2\,\pi\,.\left(\frac{t}{\mathrm{T}} - \frac{z^2\,(a+b)}{2\,a\,b\,\lambda}\right)\right\}$$

which, extended from $z = 0$ to $z = r$, gives

$$\mathrm{X} = \frac{a\,b\,\lambda}{a+b}\ \left\{\cos\lambda\left(\frac{t}{\mathrm{T}} - \frac{(a+b\,.\,r^2)}{2\,a\,b\,\lambda}\right) - \cos 2\,\pi\,\frac{t}{\mathrm{T}}\right\}$$

$$= \frac{a\,b\,\lambda}{a+b}\left\{\sin\frac{\pi\,(a+b)\,r^2}{a\,b\,\lambda}\,.\,\sin 2\,\pi\,\frac{t}{\mathrm{T}} + \left(\cos\frac{\pi\,(a+b)\,r^2}{a\,b\,\lambda} - 1\right).\,\cos 2\,\pi\,\frac{t}{\mathrm{T}}\right\}.$$

This expresses, as we have before remarked in a similar case, (Art. 718,) two partial waves differing by a quarter-undulation, and expressing it, as in that case, by $\mathrm{X} = \mathrm{X}'\,.\cos\theta + \mathrm{X}''\,.\,\sin\theta$, where $\theta = \frac{t}{\mathrm{T}}$, we find for the intensity A^2 of their resultant

$$\mathrm{A}^2 = \mathrm{X}'^2 + \mathrm{X}''^2 = 4\left(\frac{a\,b\,\lambda}{a+b}\right)^2\ \left(\sin\frac{\pi\,(a+b)\,r^2}{2\,a\,b\,\lambda}\right)^2.$$

732. Illumination of the central spot compared with the total illumination. Fresnel's theorem.

To make use of this, however, we must compare it with what would be the direct illumination of the centre of the screen, if the aperture were infinite, *i. e.* if the direct light from the luminous point shone full upon it. To this case, however, neither our formula nor our reasoning are applicable; for if we make r infinite in this expression, it becomes illusory, and presents no satisfactory sense, and in our reasoning we have neglected to consider the law of diminution of the intensity of the oblique waves, or regarded $\phi\,(\theta)$ in Art. 631 as invariable, which in this extreme case is far from the truth. We must, therefore, have recourse to another method. Now, M. Fresnel has demonstrated (and our limits oblige us to take his demonstration for granted) that this total illumination is equal to one-fourth of that which the centre of the screen would receive from an opening of such a radius, that the difference of routes of a ray passing through the centre, and one diffracted at the circumference, shall be an exact semi-undulation, *i. e.* in which $\frac{r^2\,(a+b)}{2\,a\,b} = \frac{\lambda}{2}$, or $r = \sqrt{\frac{a\,b\,\lambda}{a+b}}$. If then we substitute this for r in the above formula, and put C for the whole illumination, we get, *on the same scale*,

$$\mathrm{C} = \left(\frac{a\,b\,\lambda}{a+b}\right)^2 \cdot \left(\sin\frac{\pi}{2}\right)^2 = .\ \left(\frac{a\,b\,\lambda}{a+b}\right)^2$$

and, consequently,

$$\mathrm{A}^2 = 4\,\mathrm{C}\left(\sin\frac{\pi\,(a+b)\,r^2}{2\,a\,b\,\lambda}\right)^2.$$

733. The colours those of the reflected rings.

In this expression r, a, b are independent of λ, and therefore the value of A^2 is of the form $4\,\mathrm{C}\left(\sin 2\,\pi\,.\frac{\beta}{\lambda}\right)^2$ where $\mathrm{B} = \frac{(a+b)\,r^2}{4\,a\,b}$. Hence, if we suppose light of all colours to emanate from the luminous point, the compound tint produced in the central point of the screen will be represented by $\mathrm{S}\left\{4\,\mathrm{C}\,.\left(\sin 2\,\pi\,\frac{\beta}{\lambda}\right)^2\right\}$ and will therefore, by Art. 673, be the same with that reflected by a plate of air whose thickness is B, or $\frac{(a+b)\,r^2}{4\,a\,b}$ which increases as b diminishes when $a + b$ remains constant. Thus we see the origin of the succession of colours of the central spot in the Table above recorded, which is the more satisfactory, as that experiment was made without reference to, and indeed in ignorance of, this elegant application of M. Fresnel's general principles, the merit of which is due (as he himself states) to M. Poisson.*

734. Poisson's theorem for the illumination in the centre of a small circular shadow.

Another very curious result of M. Poisson's researches is this, that the centre of the shadow of a very small circular opaque disc, exposed to light diverging from a single point, is precisely as much illuminated by the diffracted waves as it would be by the direct light, if the disc were altogether removed. We cannot spare room for the demonstration of this singular theorem. It has been put to the test of experiment by M. Arago, with a small metallic disc cemented on a very clear and homogeneous plate of glass, and with full success.

735. Case of diffraction through two apertures very near each other. Fig. 147 and 148.

When the light is transmitted through two equal apertures, placed very near each other, the rings are formed about each as in the case of one; but besides these arise a set of narrower, straight, parallel fringes bisecting the interval between their centres, and at right angles to the line joining them. If the apertures be unequal, these fringes assume the form of hyperbolas, having the aperture in their common focus. Besides these also two other sets of parallel rectilinear fringes (in the case of equal apertures) go off in the form of a St. Andrew's cross from the centre at equal angles with the first set. See figures 147, 148. When the apertures are more numerous or varied in shape, the variety and beauty of the phenomena are extraordinary; but of this more presently.

M. Fresnel has shown, that when the light from a single luminous point is received on two plane mirrors

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* The coincidence in the higher orders of colours was, however, in our experiments less complete, and especially the green of the third order, which was wanting altogether in some cases.

736. Fresnel's experiment with two mirrors inclined to each other.

very slightly inclined to each other, so as to form two almost contiguous images, if these be viewed with a lens, there will be seen between them a set of fringes perpendicular to the line joining them. These are evidently analogous to those produced by the two holes in the experiments last described. The experiment is delicate; for if the surfaces of the reflectors at the point where they meet be ever so little, the one raised above or depressed below the other, so as to render the difference of routes of the rays greater than a very few undulations, no fringes will be seen. But it is valuable, as demonstrating distinctly that the borders of the apertures in the preceding experiment have nothing to do with the production of the fringes, the rays being in this case abandoned entirely to their mutual action after quitting the luminous point. An exactly similar set of fringes is formed if, instead of two reflectors, we use a glass, plane on one side, and on the other composed of two planes, forming a very obtuse angle, as in fig. 149. This being interposed between the eye-lens E and the luminous point S, forms two images S and S′ of it; and the interference of the rays S E and S′ E from these images, forms the fringes in question.

Fig. 149.

737. Effect of interposing a denser medium in one of two interfering rays.

Since the production of the fringes and their places with respect to the images of the luminous point, depends on the difference of routes of the interfering rays, it is evident, that if, without altering their paths, we alter the *velocity* of one of them with respect to the other, during the whole or a part of its course, we shall produce the same effect. Now, the velocity of a ray may be changed by changing the medium in which it moves. In the undulatory system, the velocity of a ray in a rarer medium is greater than in a denser. Hence, if in the path of one of two interfering rays we interpose a parallel plate of a transparent medium denser than air, (at right angles to the ray's course,) we shall increase its interval of retardation, or produce the same effect as if its course had been prolonged. If then a *thick* plate of a dense medium, such as glass, be interposed in one of the rays which form visible fringes, they will disappear; because the interval of retardation will be thus rendered suddenly equal to a great number of undulations, whereas the production of the fringes requires that the difference of routes shall be very small. If, however, only a very thin lamina be interposed, they will remain visible, but shift their places. Thus, in fig. 150, let S A, S B be rays transmitted through the small apertures A, B from the luminous point S, and received on the screen D C E, these forming a set of fringes of which C, the middle one, will be *white*. Let D, E be the dark fringes immediately adjacent on either side; and things being thus disposed, let a thin film of glass or mica G be interposed in *one* of the rays S A, its thickness being such that the ray in traversing it shall just be retarded half an undulation. Then will the rays A E, B E, which before were in complete discordance, be now in exact accordance, and there will be formed at E a bright fringe instead of a dark one. On the other hand, the ray A C will now be half an undulation behind B C, instead of in complete accordance with it, so that at C there will be formed a dark fringe, and so on. In other words, the whole system of fringes will be formed as before, but will have shifted its place, so as to have its middle in E instead of in C, *i. e.* will have moved *from* the side on which the plate of the dense medium is interposed. It is evident, that if the plate G be thicker, the same effect will take place in a greater degree.

Fig. 150.

Displacement of the fringes by it explained.

738. Mode of putting this to the test of experiment.

To make the experiment, however, it must be considered that the refractive power of glass, or indeed of any but gaseous media, is so great, that any plate of manageable thickness would suffice to displace the fringes so far as to throw them wholly out of sight. But we shall succeed, if, instead of a single plate G placed over one aperture A, we place two plates G, *g* of very nearly equal thicknesses, (such as will arise from two nearly contiguous fragments of one and the same polished plate,) one over each aperture; or we may vary the thickness of the plate traversed by either ray by inclining it, so as to bring it within the requisite limits. This done, the effect observed is precisely that described; the fringes shift their places *from* the thicker plate, without sustaining any alteration in other respects. This elegant experiment affords a strong indirect argument in favour of the undulatory system, and in opposition to that of emission, since it proves that the rays of light are *retarded* in their passage through denser media, agreeably to what the undulatory system requires, and contrary to the conclusions of the corpuscular doctrine.

Argument against the corpuscular system.

739. Arago and Fresnel's method of determining refractions of gases.

MM. Arago and Fresnel have taken advantage of this property, to measure the relative refractive powers of different gases, or of the same in different states of temperature, pressure, humidity, &c. It is manifest, that if any considerable portion of the path of *one* of the interfering rays be made to pass through a tube closed at both ends with glass plates, and the other through equal glass plates *only*, the fringes will be formed as usual. But if the tube be *exhausted*, or warmed, or cooled, or filled with a gas of different refractive density, a displacement of the fringes will take place, which (if they be received in the focus of a micrometer) may be measured with the greatest delicacy. Knowing the amount of their displacement, as compared with the breadth of the fringes, we know the number of undulations gained or lost by one ray on the other; and hence, knowing the internal length of the tube, we have the ratio of the refracting power of the medium it contains to that of air. What renders this method remarkable is, that *there is actually no conceivable limit to the precision of which it is susceptible*, since tubes of any length may be employed, and micrometers of any delicacy.

740. Fraunhofer's experiments on diffraction and interference. His apparatus.

The phenomena of diffraction, and those arising from the mutual interference of several very minute pencils of rays emanating from a common origin, have been investigated by M. Fraunhofer with great care and extraordinary precision, by the aid of a very delicate apparatus devised and executed by himself.

This apparatus consisted of a repeating, 12-inch theodolite, reading to every 4″, carrying, attached to its horizontal circle, a plane circular disc of six inches in diameter, having its axis precisely coincident with that of the theodolite, and having its own particular divisions independent of those of the theodolite. In the centre of this disc was placed vertically a metallic screen, having in it one or more narrow, vertical, rectangular slits, or other apertures, and so fixed as to have the middle of its aperture, or system of apertures, exactly coincident with the axis of the instrument. Attached to the great circle of the theodolite, horizontally, was a telescope, having its object-glass three inches and a half from the centre, and its axis directed exactly to it, and precisely parallel to the plane of the limb, and provided with a delicate micrometer, whose parallel threads were exactly vertical.

Part III.

The instrument being insulated on a support of stone, a beam of solar light was directed by a heliostat, through a very narrow slit, also exactly vertical, having a breadth of one hundredth of an inch, and distant 463½ inches from the centre of the theodolite, so as to fall on the screen, and, being transmitted through its apertures, to be received into the telescope. It is manifest that the eye-glass of the telescope will here view the fringes, &c. as they are formed in its focus. The magnifying power of the telescope used by Fraunhofer varied from 30 to 50 times.

741. Fringes produced by a single narrow aperture.

M. Fraunhofer first examined the effect produced by the diffraction of the light through a single slit,—the breadth of which he first determined with the greatest precision by means of a micrometer-microscope, with which he assures us that he found it practicable to appreciate so minute a quantity as 1-50,000th of an inch. The slit being then placed on the apparatus, and accurately adjusted before the object-glass of the telescope, which was directed exactly to the aperture in the heliostat, the image of the latter was formed in its focus, accompanied by lateral fringes, which by the effect of the magnifying power were dilated into broad and brilliant prismatic spectra. The distances of the red ends of these spectra from the middle point, or white central image, were then measured accurately by means of the micrometer. The result of a great number of experiments with apertures of all breadths from one-tenth to one-thousandth of an inch, agreed to astonishing precision with each other, and with the following laws, *viz.* that (under the circumstances of the experiment,)

Their laws and dimensions.

1. *The angles of deviation of the diffracted rays, forming similar points of the systems of fringes produced by different apertures, are inversely as the breadths of the apertures.*

2. *That the distances of similar rays (the extreme red, for instance,) from the middle in the several spectra, constituting the successive fringes, form in each case an arithmetical progression whose difference is equal to its first term.*

3. That calling γ the breadth of the aperture, in fractions of a Paris inch, the angular distances L', L'', L''', &c. in parts of a circular arc to radius unity, of the extreme red rays in each fringe from the middle line, are respectively represented by $L' = \frac{L}{\gamma}$, $L'' = 2 \cdot \frac{L}{\gamma}$, $L''' = 3 \cdot \frac{L}{\gamma}$, &c. where $L = 0.0000211$, and a similar law holds for all the other coloured rays, different values being assigned to L for each.

742. Newton's experiment with two knife edges.

This conclusion agrees perfectly with the result of an experiment related by Newton in the IIId Book of his *Optics.* He ground two knife edges truly straight, and placed them opposite to each other, so as to be in contact at one end, and at the other to be at a small distance, such that the angle included between them was about 1° 54′, thus forming a slit whose breadth at their intersection was evanescent, and at 4 inches from that point ¼th of an inch, and in the intermediate points, of course, of every intermediate magnitude. Exposing this in a sunbeam emanating from a very small hole at 15 feet distance, he received their shadows on a white screen behind them, and observed that when they were received very near to the knife edges, (as at half an inch,) the fringes exterior to the shadow of each edge ran parallel to its border without sensible dilatation, till they met and joined without crossing, at angles equal to that contained between the knife edges. But when the shadows were received at a great distance from the knives, the fringes had the form of hyperbolas, having for one asymptote the shadow of the knife to which they respectively belonged, and for the other a line perpendicular to that bisecting the angle of the two shadows, each fringe becoming broader and more distinct from the shadow which it bordered, as it approached the angle. These hyperbolas crossed without interfering, as represented in fig. 151. Their points of crossing, Newton found, however, not to be at a constant distance from the angle included between the projections of the knife edges, but to vary in position with the distance from the knives, at which the shadow is received on the screen; and hence, he says, "I gather that the light which makes the fringes upon the paper, is not the same light at all distances of the paper from the knives; but when the paper is held very near the knives, the fringes are made by light which passes by their edges at a less distance, and is more bent than when the paper is held at a greater distance from the knives." Newton, however, left these curious researches, which could hardly have failed to have led in his hands to a complete knowledge of the principles of diffraction—unfinished; being, as he says, interrupted in, and unwilling to resume them: doubtless, owing to the chagrin and opposition his optical discoveries produced to him. An unmeet reward, it must be allowed, for so noble a work, but one of which, unhappily, the history of Science affords but too many parallels.

Fig. 151

743. Case when the edges of the aperture were at different distances from the origin of the light.

The above were the results obtained by M. Fraunhofer when the two edges of the aperture were both in a plane perpendicular to the incident rays; but when the same effective breadth was procured, by inclining a larger aperture obliquely, so as to reduce its actual breadth in the ratio of the cosine of its incidence to radius, or by limiting the incident ray by two opaque edges at different distances from the object-glass of the telescope, the phenomena were very different. To accomplish this, two metallic plates were fixed upright on the horizontal plate of the theodolite, having their edges exactly vertical, and precisely at opposite extremities of a diameter. Then, by turning the plate round on its axis, the passage allowed to the light between them could be increased or diminished at pleasure. The phenomena, then, were as follows. When the opening allowed to the light was considerable, as 0.02 or 0.04 inch (Paris,) the fringes were exactly similar to those observed when the edges were equidistant from the object-glass; but as the opening diminished, they ceased to be symmetrical on both sides of the middle line, those on the side of that edge of the aperture nearest to the telescope becoming broader than those on the other, which, on their part, undergo no sensible alteration. As the aperture contracts, this inequality increases, till at length the dilated fringes begin to disappear in succession, the outermost first, which they do by suddenly acquiring an extraordinary magnitude, so as to fill the whole field of the telescope, and thus, as it were, losing themselves. While these are thus vanishing, those on the other side remain quite unaltered till the last is gone, when they all disappear at once, which happens at the moment that the opening is reduced to nothing by the two edges covering each other.

ight.

744. se of a all, circu- aperture.

When the aperture placed before the object-glass, instead of being a straight line, was a small, circular hole, and the aperture of the heliostat, in like manner, a minute circle, the phenomena of the rings were observed, and their diameters could be accurately measured by the micrometer. The results of these measurements led M. Fraunhofer to the following laws: 1st, that for apertures of different diameters, the diameters of the rings are inversely as those of the apertures forming them; 2dly, that the distances from the centre of the maxima of extreme red rays (or of rays of any given refrangibility) in the several rings of one and the same system, form an arithmetical progression, whose difference is somewhat less than its first term. Thus, calling γ the diameter of the aperture, and putting $L = \frac{0.0000214}{\gamma}$ and $l = \frac{0.0000257}{\gamma}$, he found $L' = l$, $L'' = l + L$, $L''' = l + 2L$, &c., where L' L'', &c. represent the angular semidiameters of the several rings expressed in arc of a circle to radius unity. The near coincidence of the value of L in this case, with that in the case of a linear aperture, and the small, but decided difference of the values of the first term of the progression in the two cases, are very remarkable.

745. Case of a very narrow, annular aperture.

When the aperture was a very narrow, circular annulus, such as might be traced with a steel point on a gilt disc of glass, of whatever diameter, the image was a circular spot, surrounded in like manner by coloured rings, the diameters of which depended nowise on the *diameter*, but only on the *breadth* of the annulus, being in fact (as might be expected) the very same as the intervals between similar opposite fringes, on both sides of the central line in the image produced by a linear aperture of equal breadth.

746. Interference of many rays passing through gratings.

But the most curious parts of M. Fraunhofer's investigations are those which relate to the interference of rays transmitted through a great many narrow apertures at once. When these apertures are exactly equal, and placed at exactly equal distances from one another, phenomena of a totally different kind from those originating in a single aperture are seen. In his first experiments of this kind he formed a *grating* of wire, by stretching a very fine wire across a frame, in the form of a narrow, rectangular parallelogram, whose shorter sides were screws tapped in the same die, and therefore precisely similar; across these screws in the consecutive intervals between their threads the wires were stretched, and of course could not be otherwise than parallel and equidistant. The diameter of the wire was 0.002021 Paris inch, the intervals between them each 0.003862, and the grating consisted of 260 such wires. When this apparatus was placed precisely vertical before the object-glass of the telescope, and illuminated by a narrow line of light 0.01 inch in breadth, also exactly vertical, forming the aperture of the heliostat, the image of this was seen in the telescope, colourless, well defined, and in all respects precisely as it would have been seen without the interposition of any grate or aperture at all, occupying the centre of the field, only less bright. On either side of this was a space perfectly dark, after which succeeded a series of prismatic spectra, which he calls spectra of the second class, not consisting of tints melting into each other, according to the law of the coloured rings, or any similar succession of hues depending on a regular degradation of light, but of perfectly *homogeneous* colours; so much so, as to exhibit the same dark lines crossing them as exist in the purest and best defined prismatic spectrum. In the disposition of things already described, the first, or nearer spectrum is completely insulated, the space between it and the central image, as well as between it and the second spectrum, being quite dark. The violet ends of the spectra are inwards, and the red outwards; but the violet end of the third spectrum is superposed on the red end of the second, so as in place of a dark interval to produce a purple space; and as we proceed farther from the middle, the spectra become more and more confounded, but not less than thirteen may easily be counted on each side by the aid of a prism refracting them transversely, so as to separate their overlapping portions.

Spectra of the second class.

747. Ratio of the coloured spaces in them.

The measurement of the distances of similar points in the several spectra are rendered susceptible of the utmost precision by means of the dark lines which cross them. A very remarkable peculiarity of these spectra must, however, be here noticed, *viz.* that although the dark lines hold exactly the same places in the order of colours, or, in other words, correspond to precisely the same *degrees of refrangibility*, as in the prismatic spectra formed by refraction, yet the ratio of the intervals between them, or the breadths of the several coloured spaces, differ entirely in the two cases. Thus, in the diffracted spectra, the interval between the lines C and D (fig. 94) is very nearly double of that between G and H, while in a spectrum formed by a flint-glass prism of an angle of 270, the proportion is reversed, and in a water prism of the same angle C D : G H : : 2 : 3.

748. Their laws.

In the diffracted fringes formed by a single aperture, their distances (as we have seen) from the axis depends only on the breadth of the aperture, being inversely as that breadth. In the spectra formed by a great number, their distances from the central image depends neither on the breadths of the apertures nor on the intervals between them, but on the sum of these quantities, that is, on the distances between the middle points of the consecutive apertures, (or, in the case before us, on the distances between the axes of the wires.) By a series of measures performed with the utmost care and precision on wire gratings of a great variety of dimensions, M. Fraunhofer ascertained the following laws and numerical values.

749. 1. For different gratings, if we call γ the breadth of each of the interstices through which the light passes, a δ that of each of the opaque intervals between them, the magnitudes of spectra of the same order, and the d tances of similar points in them from the axis, is inversely as the sum $\gamma + \delta$.

750. 2. The distances of similar points, (*i. e.* of similar colours or similar fixed lines,) in the several consecu spectra formed by one and the same grating from the axis, constitute an arithmetical progression whose differe is equal to its first term.

751. 3. For the several refrangibilities corresponding to the fixed lines B, C, D, E, &c. the first term of this gression is numerically represented by the respective fractions which follow, being the lengths of the ar their sines to radius unity.

$$B = \frac{0.00002541}{\gamma+\delta}; \qquad E = \frac{0.00001945}{\gamma+\delta}; \qquad H = \frac{0.00001464}{\gamma+\delta}.$$

$$C = \frac{0.00002422}{\gamma+\delta}; \qquad F = \frac{0.00001794}{\gamma+\delta}; \text{ \&c.}$$

$$D = \frac{0.00002175}{\gamma+\delta}; \qquad G = \frac{0.00001587}{\gamma+\delta};$$

752. Case of extremely close gratings. Methods of constructing them.

These results were all, however, deduced from gratings so coarse as to allow of our regarding the angles of diffraction as proportional to their sines; but when extremely fine gratings are employed, the spectra are formed at great distances from the axis, and the analogy of other similar cases, as well as theory, would lead us to substitute sin B, sin C, sin D, &c. in the place of B, C, D, &c. This, M. Fraunhofer found by experiment to be really the case. The construction of gratings proper for these delicate purposes, however, was no easy matter. Those employed by him were nothing more than a system of parallel and equidistant lines ruled on plates of glass covered with gold-leaf, or with the thinnest possible film of *grease;* by the former of these methods he found, that the proximity of the lines might be carried to the extent of placing about a thousand in the inch, but when he would draw them still closer, the whole of the gold-leaf was scraped off. When the surface was covered with a film of grease so thin as to be almost imperceptible to the sight, (although the intervals were in this case transparent,) no change was produced in the optical phenomena, so far as the spectra were concerned, only the brightness of the central image being increased. By this means he was enabled to obtain a system of parallel lines at not more than half the distance from each other that could be produced on gold-leaf: but beyond this degree of proximity, he found it impossible to carry the ruling of equidistant lines on any film of grease or varnish. But this being still far short of his wishes, he had recourse to actual engraving with a diamond point on the surface of the glass itself, and by this means was enabled to rule lines so fine as to be absolutely invisible under the most powerful compound microscope, and so close that 30,000 of them lie in a single Paris inch. When so excessively near, however, no accuracy of machinery will ensure that perfect equidistance which is essential to the production of the spectra now under consideration, and he found it impossible to succeed in placing them nearer than 0.0001223, (or about 8200 to the inch,) with such a degree of precision as to enable him to distinguish the fixed lines in the spectra; and, if it be considered, that a deviation to the extent of the hundredth part of the just interval frequently occurring, is sufficient to obliterate these, and that to produce the spectra in sufficient brightness to affect the eye, some hundreds or even thousands must be ruled, we shall be enabled to form some conception of the difficulties to be encountered in researches of this kind. For a detail of some of these, and of the methods employed by him to count their number and measure their distances, we must refer to his original Memoir, (read to the Royal Bavarian Academy of Sciences, June 14, 1823.)

753. The spectra modified by the form of the striæ in the gratings.

In the course of these researches, M. Fraunhofer met with a very singular and instructive peculiarity in one of the engraved glass-gratings used by him; which, although it produced spectra equidistant on either side of the axis, yet gave always those on one side a much greater degree of brightness than those on the other. Attributing this to the *form* of the furrows being sharper terminated on one side than on the other, owing either to the figure of the diamond point or the manner of its application, he endeavoured to produce a similar structure of the striæ in a film of grease spread on glass, by purposely applying the engraving tool obliquely, and the attempt proved successful.

754. Case of inclined gratings. Unsymmetrical spectra of the second class.

When the incident rays from the opening in the heliostat fell obliquely on the grating, it might be supposed that the phenomena would be the same as those exhibited by a closer grating, having intervals less in proportion of the cosine of the angle of incidence to radius. But the analogy of the unsymmetrical fringes produced by a single aperture, whose sides lie in a plane oblique to the incident ray, may lead us to expect a different result, and experiment confirms the surmise; thus, M. Fraunhofer found, that on inclining a grating, whose intervals $(\gamma+\delta)$ were each equal to 0.0001223 inch, so as to make the angle of incidence 55° with the perpendicular, the distance of the first fixed line D from the axis on the one side of the axis was 15° 6′, and on the other no less than 30° 33′, or more than double.

755. Theoretical considerations.

The facts deduced by M. Fraunhofer in the above detailed researches are certainly extremely curious. The most interesting and remarkable point about them is the perfect homogeneity of colour in the spectra, indicating a saltus, or breach of continuity, in the law of intensity of each particular coloured ray in the diffracted beam. For it is obvious, that taking any one refrangibility (that corresponding to the fixed line C, for example,) the expression of its intensity in functions of its distance from the axis must be (analytically speaking) of such a nature as to vanish completely for every value of that distance, excepting for a certain series in arithmetical progression, or, as it is called, a *discontinuous* function; so that the curve representing such value, having the distance from the axis for its abscissa, must be a series of points arranged above the axis at equal intervals; or, at least, a curve of the figure represented in fig. 151, in which certain extremely narrow portions, equidistantly arranged, start up to considerable distances from the axis, while all the intermediate portions lie so close to that line as to be confounded with it. The manner in which such a function can be supposed to originate from the summation of a series of the values of $\int d\nu \,.\, \sin \frac{\pi}{2} \nu^2$ and $\int d\nu \,.\, \cos \frac{\pi}{2} \nu^2$, (Art. 718,) taken successively between limits corresponding to the boundaries of the several interstices, involves too many complicated considerations to enter into in this place. M. Fraunhofer, meanwhile, states the following general expression, as the result of his own investigations founded on the principle of interferences. Let n indicate the order of any spectrum, reckoned from the axis; ϵ the distance from the middle of one interstice to that of the adjacent one $= \gamma + \delta$; λ the length of an undulation of an homogeneous ray; σ the angle of incidence of the ray from the luminous point on the grating; and y the length of a perpendicular let fall from the micrometer thread of the telescope, (or from the point in the focus of its object-glass, where that particular homogeneous ray in that spectrum is found,) on the plane of the grating. Then, if the angular elongation of that ray from the axis be called $\theta^{(n)}$, we shall have, in general,

$$\text{cotan}\,\theta^{(n)} = \frac{\sqrt{\{\epsilon^2 - (\epsilon\,.\,\sin\sigma + n\lambda)^2\}\,.\,\{4y^2 + \epsilon^2 - (\epsilon\,.\,\sin\sigma + n\lambda)^2\}}}{2y(\epsilon\,.\,\sin\sigma + n\lambda)}.$$

In this equation, n is to be regarded as + for the spectra which lie on the side of the axis on which the incident ray makes an obtuse angle with the plane of the grating, and negative for the spectra on the other side. This formula he states to be rigorous, and independent of any approximation. When y is very great (as it, in fact, always is,) compared with ϵ and λ, this reduces itself simply to

$$\text{cotan}\,\theta^{(n)} = \frac{\sqrt{\epsilon^2 - (\epsilon\,.\,\sin\sigma + n\lambda)^2}}{\epsilon\,.\,\sin\sigma + n\lambda},\ \text{or}\ \sin\theta^{(n)} = \frac{\epsilon\,.\,\sin\sigma + n\lambda}{\epsilon}.$$

756. Lengths of undulations of the rays B, C, D, &c. assigned by Fraunhofer.

This formula, applied to M. Fraunhofer's measures of the distances of the same fixed lines in successive spectra on either side of the axis, in the case of inclined gratings, represents them with perfect exactness. When the gratings are perpendicular to the ray $\sigma = 0$, and the equation becomes $\sin t^{(n)} = \frac{n\lambda}{\epsilon}$, which is the law before noticed for symmetrical spectra. And hence, too, it appears that the values of λ, or the lengths of the undulations for the several rays designated by C, D, E, &c., are no other than the numerators of the fractions in Art. 751 expressed in parts of a Paris inch, which thus become data of the utmost value in the theory of light, from the great care and precision with which they have been fixed, and for the possibility of identifying them at all times.

757. Diffracted spectra produced by reflexion.

If the unruled surface of the glass grating be covered with black varnish, and the light reflected from the ruled surface be received in the telescope, the very same phenomena are seen as if the light had been transmitted through the glass, and the same analytical expression, according to M. Fraunhofer, applies to both cases.

758. Alleged limit to the powers of microscopes.

A curious consequence of this expression is, that if ϵ, the distance between the lines, be less than λ, and the light fall perpendicularly on the grating, so that $\sin\sigma = 0$, we shall have $\sin\theta^{(n)} > 1$, and therefore $\theta^{(n)}$ imaginary. It appears, therefore, that lines drawn on a surface distant from each other by a less quantity than one undulation of a ray of light, produce no coloured spectra. Hence, such scratches, or inequalities, on polished surfaces, have no effect in disturbing the regularity of reflexion or refraction, and produce no dimness or mistiness in the image; if less distant from each other than this limit. M. Fraunhofer seems inclined to conclude further, that an object of less linear magnitude than λ can in consequence never be discerned by microscopes, as consisting of parts: a conclusion which would put a natural limit to the magnifying power of microscopes, but which we cannot regard as following from the premises.

759. Spectra produced by composite gratings.

When the intervals of the parallel interstices are unequal, and disposed with no regularity, the light of the diffracted spectra of different combinations is confounded together, and a white misty streak at right angles to the direction of the lines arises; but when they are *regularly unequal*, so that the same intervals recur in regular periods, if we call E $(= \epsilon' + \epsilon'' + \epsilon''' + \text{\&c.})$ the interval between any two distant by a whole period, we shall have, for the law of the lateral spectra, the equation $\sin\theta^{(n)} = \frac{n\lambda}{E}$. And the spectra so formed, are still observed to consist of homogeneous light, exhibiting the fixed lines with great distinctness. A very curious, and, as far as concerns the practical measurement of the phenomena, useful observation has been made by M. Fraunhofer on the spectra so formed by these *composite* gratings, *viz.* that although they follow the same law in respect of their distances from the axis, yet the successive spectra differ greatly in intensity, some being so faint as to be scarce perceptible, while the immediately adjacent ones will often be very intense. Owing to this cause, spectra of the higher orders, which in a simple grating the interval of whose interstices is represented by E, are confused and obliterated by the encroachment of those adjacent, are often very distinct when formed by a *composite* grating, the period of recurrence of whose similar interstices is $E = \epsilon' + \epsilon'' + \epsilon''' + \text{\&c.}$ Thus, M. Fraunhofer was never able through a simple grating to see the fixed lines C and F in the spectrum of the 12th order, reckoning from the axis, while in a composite grating, consisting of three systems of lines continually repeated, whose intervals ϵ', ϵ'', ϵ''' were to each other as 25 : 33 : 42, these fixed lines as well as the lines D and E, were distinctly seen in the 12th spectrum, owing to the almost total disappearance of the 10th and 11th. Nay, even the fixed line E in the 24th spectrum could be seen, and its distance from the axis measured with this grating.

Singular phenomenon noticed by Fraunhofer respecting the intensity of the spectra.

760. Various stages of the phenomena. Spectra of the first class

Such are the extreme cases of the phenomena as produced by a single aperture, and by an infinite, or, least, very great number; but the intermediate steps and gradations by which one set of phenomena pass into t other, remain to be traced. When a single interstice is left open in a grating, the spectra are formed as describ in Art. 741. These, M. Fraunhofer calls *spectra of the first class*, and their colours are not homogeneous, graduate into one another.

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When two contiguous interstices are left open, the spectra of the first class appear as before; but between axis and the first spectrum on either side appear other spectra, which M. Fraunhofer terms imperfect spect the second class, their colours being similar to those of the first class, and no fixed lines being visible in t

Spectra of the third class.

When three adjacent interstices are left open, a third set of spectra, or *spectra of the third class*, are formed between the axis and the nearest of the imperfect spectra of the second class. Besides these, no new *classes* of spectra arise by a further increase of the number of interstices; but these undergo a series of modifications as the interstices grow more numerous. These are chiefly as follows:

762. Modifications of these spectra by increasing the number of interfering rays.

The spectra of the third class grow narrower, and approach the axis, till at last they run together and form by their union the colourless, well-defined image of the opening of the heliostat in the axis of the whole phenomenon. By a series of exact measurements, M. Fraunhofer found their breadths to be inversely as the number of interstices by which they are produced in the same grating, and inversely as the intervals of the interstices for different ones; and in general, that $\gamma + \delta = \epsilon$ representing this interval, m the number of interstices used, and n the *order* of the spectrum, $\theta^{(n)}$ the distance of extremity of the red rays in that spectrum is given by the equation

Formula for spectra of third class.

$$\theta^{(n)} = \frac{n}{m} \times \frac{0.0000208}{\epsilon}.$$

763. Transition from imperfect to perfect spectra of second class.

As the spectra of the third class contract into the axis, they leave a dark space between it and the first spectrum of the second class. This and the other spectra of that class meanwhile grow continually more vivid and homogeneous in respect of colour; till at length, when the number of interfering rays is very much increased, the fixed lines begin to appear in them, and they acquire the character of *perfect* spectra of the second class.

764. Phenomena of gratings immersed in fluids.

M. Fraunhofer next examined the phenomena produced by immersing in media of different refractive powers the gratings used, when he found all the phenomena precisely similar; but the distances at which the several spectra were formed from the axis, to be less than when in air, in the inverse ratio of the refractive indices.

765. Substitution of very minute apertures for gratings.

A very beautiful and splendid class of optical phenomena has been investigated and described by M. Fraunhofer, which arise by substituting for the gratings used in the above experiments very small apertures of regular figures, such as circles and squares, either singly or arranged in regular forms, in great numbers; as, for instance, when two equal wire gratings are crossed at right angles. Fig. 151 is a representation of the phenomenon produced when the light is received on the object-glass of the telescope through two circular holes of the diameter 0.02227 inch, placed at a distance of 0.03831 inch centre from centre. Each compartment is a separate spectrum. In the bands *a a*, *b b* we see here plainly the origin and minute structure of the vertical and crossed fringes described in Art. 735. The appearances vary as the number of apertures is increased, the spectra growing purer and more vivid. That which arises when two equal wire gratings are crossed, is figured in M. Fraunhofer's work, and is one of the most magnificent phenomena in Optics.

766. Rings seen about the stars in telescopes.

When we look at a bright star through a very good telescope with a low magnifying power, its appearance is that of a condensed, brilliant mass of light, of which it is impossible to discern the shape for the brightness; and which, let the goodness of the telescope be what it will, is seldom free from some small ragged appendages or rays. But when we apply a magnifying power from 200 to 300 or 400, the star is then seen (in favourable circumstances of tranquil atmosphere, uniform temperature, &c.) as a perfectly round, well-defined planetary disc, surrounded by two, three, or more alternately dark and bright rings, which, if examined attentively, are seen to be slightly coloured at their borders. They succeed each other nearly at equal intervals round the central disc, and are usually much better seen and more regularly and perfectly formed in refracting than in reflecting telescopes. The central disc, too, is much larger in the former than in the latter description of telescope.

767. Spurious discs of the stars.

These discs were first noticed by Sir William Herschel, who first applied sufficiently high magnifying powers to telescopes to render them visible. They are not the real bodies of the stars, which are infinitely too remote to be ever visible with any magnifiers we can apply; but *spurious*, or unreal images, resulting from optical causes, which are still to a certain degree obscure. It is evident, indeed, to any one who has entered into what we have said of the law of interferences, and from the explanation given in Art. 590 and 591 of the formation of *foci* on the undulatory system, that (supposing the mirror or object-glass rigorously aplanatic) the focal point in the axis will be agitated with the united undulations, in complete accordance, from every part of the surface, and must, of course, appear intensely luminous; but that as we recede from the focus in any direction in a plane at right angles to the axis, this accordance will no longer take place, but the rays from one side of the object-glass will begin to interfere with and destroy those from the other, so that at a certain distance the opposition will be total, and a dark ring will arise, which, for the same reason, will be succeeded by a bright one, and so on. Thus the origin both of the central disc and the rings is obvious, though to calculate their magnitude from the data may be difficult. But this gives no account of one of the most remarkable peculiarities in this phenomenon, *viz.* that the apparent size of the disc is different for different stars, being uniformly larger the brighter the star. This cannot be a mere illusion of judgment; because when two unequally bright stars are seen at once, as in the case of a close double star, so as to be directly compared, the inequality of their spurious diameters is striking; nor can it be owing to any real difference in the stars, as the intervention of a cloud, which reduces their brightness, reduces also their apparent discs till they become mere points. Nor can it be attributed to irradiation, or propagation of the impression from the point on the retina to a distance, as in that case the light of the central disc would encroach on the rings, and obliterate them; unless, indeed, we suppose the vibrations of the retina to be performed according to the same laws as those of the ether, and to be capable of interfering with them; in which case, the disc and rings seen on the retina will be a resultant system, originating from the interference of both species of undulations.

Explanation of the rings on the principle of interferences.

768. Phenomena produced by apertures of various figures.

Not to enter further, however, on this very delicate question, we shall content ourselves with stating some of the phenonena we have observed, as produced by diaphragms, or apertures of various shapes variously applied to mirrors and object-glasses, and which form no inapt supplement to the curious observations of Fraunhofer on the effect of *very minute* apertures, of which they are in some sort the converse.

769. Circular apertures. When the whole aperture of a telescope is limited by a *circular* diaphragm, whether applied near to, or at a distance from, the mirror or object-glass, the disc and rings enlarge in the inverse proportion of the diameter of the aperture. When the aperture was much reduced (as to one inch, for a telescope of 7 feet focal length) the spurious disc was enlarged to a planetary appearance, being well defined, and surrounded by one ring only, strong enough to be clearly perceived, and faintly tinged with colour in the following order, reckoning from the centre of the disc. White, very faint red, black, very faint blue, white, extremely faint red, black. When the aperture was reduced still farther (as to half an inch) the rings were too faint to be seen, and the disc was enlarged to a great size, the graduation of light from its centre to the circumference being now very visible, giving it a hazy and cometic appearance, as in fig 152. Fig. 152.

770. Annular apertures. When annular apertures were used the phenomena were extremely striking, and of great regularity The exterior diameter of the annulus being three inches, and the interior $1\frac{1}{4}$, the appearance of Capella was as in fig. 153, and of the double star Castor, as in 154. As the breadth of the annulus is diminished, the size of the disc and breadth of the rings diminish also, (contrary to what took place in Fraunhofer's experiments with extremely narrow annuli, and obviously referring the present phenomena to different principles,) at the same time the number of visible rings increases. Fig. 153 to 157. Fig. 155, 156, and 157 exhibit the appearance of Capella with annular apertures of 5.5 inch $-$ 5 inch (*i. e.* whose exterior diameter $= 5.5$ and interior $= 5$) of $0.7-0.5$, of $2.2-2.0$. In the last case the disc was reduced to a hardly perceptible round point, and the rings were so close and numerous as scarcely to admit being counted, giving, on an inattentive view, the impression of a mere circular blot of light. When the breadth of the annulus was reduced to half this quantity, the intervals between the rings could no longer be discerned. The dimensions of the rings and disc, generally, seem to be proportional to $\frac{r'-r}{r}$.

771. Another set of rings. Fig. 158 and 159. Besides the rings immediately close to the central disc, however, others of much greater diameter and fainter light, like halos, are seen with annular apertures, which belong (in Fraunhofer's language) to spectra of a different class. With a single annulus they are too faint to be distinctly examined, but with an aperture composed of two annuli, as in fig. 158, they are very distinct and striking, presenting the phenomenon in fig. 159, (in which it is to be understood that light is represented in the engraving by darkness, and darkness by light.)

772. Image produced by a triangular aperture. When the aperture was in the form of an equilateral triangle, the phenomenon was extremely beautiful; it consisted of a perfectly regular, brilliant, six-rayed star, surrounding a well-defined circular disc of great brightness. The rays do not unite to the disc, but are separated from it by a black ring. They are very narrow, and perfectly straight; and appear particularly distinct in consequence of *the total destruction of all the diffused* light which fills the field when no diaphragm is used; a remarkable effect, and much more than in the mere proportion of the light stopped. Fig. 160. Fig. 160 is a representation of this elegant appearance. The same arises when, in place of an equilateral triangle, the aperture is the difference of two concentric, equilateral triangles similarly situated.

773. When out of focus. As a triangle has but three sides and three angles, it seems singular that a *six*-rayed star should be produced. Supposing three to arise from the angles, and three from the sides, it might be expected that some sensible difference should exist in the alternate rays, marking their different origin. When the telescope is in perfect focus, however, all the rays are precisely alike; but if thrown out of focus, their difference of origin becomes apparent. Fig. 161. Fig. 161 represents the phenomenon then seen, in which the alternate branches are seen to consist of a series of fringes parallel to their length, and the others of small arcs of similar fringes immediately adjacent to the vertices of the hyperbolas to which they belong, and which consequently cross the rays in a direction perpendicular to their length. As the telescope is brought better in focus, the hyperbolas approach their asymptotes, and are confounded together in undistinguishable proximity; and thus three rays arise composed of continuous lines of light, and three intermediate ones composed of an infinite number of discontinuous points placed infinitely near each other. To represent analytically the intensity of the light in one of these *discontinuous* rays would call for the use of functions of a very singular nature and delicate management.

774. Application to the construction of a position-micrometer. The phenomenon just described affords in certain cases a very perfect position-micrometer for astronomical uses. If the diaphragm be turned round, the rays turn with it; and if a brilliant star (as α Aquilæ) have near it a very small one, the diaphragm may be so placed as to make one of the rays pass through the small star, which thus remains like a bead threaded on a string, and may be examined at leisure. If then the position of the diaphragm be read off on a graduation properly contrived, the relative situations of the two stars become known. We have satisfied ourselves by trial of the practicability of this; and by proper contrivances the principle may be made available in cases which at first sight appear to present considerable difficulties.

775. Three circular apertures. Fig. 162. When three circular apertures, having their centres at the angles of an equilateral triangle, were used, the image consisted of a bright central disc. Six fainter ones in contact with it, and a system of very faint halo-like rings surrounding the whole as in fig. 162. When, however, three equal and similar *annular* apertures were thus disposed, the appearance when *in focus* was as in fig. 153, being exactly the same as if two of them were closed. But when thrown a little out of focus, the difference was perceived. Fig. 163. Fig. 163 represents the appearance in this case, each of the apertures then produces its own central disc and system of rings, whose intersections give rise to the system of intersectional fringes there depicted. As the telescope is brought better in focus these disappear, and the phenomenon is as in fig. 164; the centres gradually approaching, and the rings blending till the point of complete coincidence is attained. Fig. 164.

776. An aperture in the form of the difference between two concentric squares produced not an eight, but a four-rayed star. The rays, however, were not, as in the case of the triangular aperture, uninterrupted fine lines, gradually tapering away from the centre to their extremities, but composed of distinct alternating obscure and

bright portions, as represented in fig. 165. The portions nearest the central disc (which is circular) were composed of bands transverse to the direction of the rays, and tinged with prismatic colour. Similar bands, no doubt, existed in the more distant portions, which extended to a great length.

Square apertures. Fig. 165.

777. Effect of very numerous square apertures Fig. 166.

An aperture consisting of fifty squares, each of about half an inch in the side, regularly disposed at intervals so as to leave spaces between them in both directions equal in breadth to the side of each, produced an image totally different from that described by Fraunhofer as resulting from the crossing of two equal very close gratings, though the distribution and shape of the apertures were the same in both cases. It was as represented in fig. 166, consisting of a white, round, central disc, surrounded by eight vivid spectra, disposed in the circumference of a square, beyond which were arranged in the shape of a cross, triple lines of very faint spectra extending to a great distance.

778. Fig. 167.

When the aperture consisted of numerous equilateral triangles regularly disposed, as in fig. 167, the image presented the very beautiful phenomenon represented in fig. 168, consisting of a series of circular discs arranged in six diverging rays from the central one, and each surrounded with a ring. The central disc was colourless and bright; the rest more and more strongly coloured and elongated into spectra, according to their degree of remoteness from the centre. These are only a few of the curious and beautiful phenomena depending on the figures of the apertures of telescopes, which afford a wide field of further inquiry, and one at least as interesting to the artist as to the philosopher.

PART IV.

OF THE AFFECTIONS OF POLARIZED LIGHT.

§ I. *Of Double Refraction.*

779. Exceptions to the law of ordinary refraction numerous.

WHEN a ray of light is incident on the surface of a transparent medium, a portion of it is reflected, at an angle equal to that of incidence, another small portion (so small, however, that we shall neglect its consideration) is dispersed in all directions, serving to render the surface visible, and the rest enters the medium and is refracted. The *law* of refraction, or the rule which regulates the path of this portion within the medium, has been explained in the preceding parts; and no exceptions to it, as a general law, have hitherto been noticed. It is, however, very far from general; and, in fact, obtains only where the refracting medium belongs to one or other of the following classes, *viz.*

Classes of bodies in which it holds.

Class 1. Gases and vapours.
2. Fluids.
3. Bodies solidified from the fluid state too suddenly to allow of the regular crystalline arrangement of their particles, such as glass, jellies, &c., gums, resins, &c., being chiefly such as in the act of cooling pass through the viscous state.
4. Crystallized bodies, having the cube, the regular octohedron, or the rhomboidal dodecahedron for their primitive form, or which belong to the *tessular* system of Mohs. A very few exceptions (probably only apparent ones, arising from our imperfect knowledge of crystallography) exist to the generality of this class.

The solid bodies belonging to these classes, moreover, cease to belong to them when forcibly compressed or dilated, either by mechanical violence, or by the unequal action of heat or cold, which brings their particles into a state of strain, such as in extreme cases to produce their disruption, as is familiarly seen in the cracking of a piece of glass by heat too suddenly and partially applied. The class of fluids too admits some exceptions, at least when very minutely considered; but the deviation from the ordinary law of refraction in these cases is of so microscopic a kind, that we shall at present neglect to regard it.

780. Double refraction.

All other bodies, comprehending all crystallized media, such as salts, gems, and crystallized minerals, not belonging to the system above mentioned; all animal and vegetable bodies in which there is any disposition to a regular arrangement of molecules, such as horn, mother of pearl, quill, &c.; and, in general, all solids when in a state of unequal compression or dilatation, act on the intromitted light according to very different laws, dividing the refracted portion *into two distinct pencils*, each of which pursues a rectilinear course so long as it continues within the medium, according to its own peculiar laws, but without further subdivision. This phenomenon is termed double refraction. It is best and most familiarly seen in the mineral termed Iceland spar, which is, in fact, carbonate of lime in a regular crystalline form. This is generally obtained in oblique parallelepipeds, easily reduced by cleavage to regular, obtuse rhomboids, and is not uncommonly met with in a state of limpid transparency, on which account, as well as by reason of its remarkable optical properties, it easily attracted attention. Bartholinus, in 1669, appears to have been the first to give any account of its double refraction, which was afterwards more minutely examined by Huygens, the first proposer of the undulatory theory of light, whose researches on this phenomenon form an epoch in the history of Physical Optics little if at all less important than the great discovery of the different refrangibility of the coloured rays by Newton. To Huygens we owe the discovery of the law of double refraction in this species of medium. Newton, misled by some inaccurate measurements, (a thing most unusual with him,) proposed a different one; but the conclusions of Huygens, long and unaccountably lost sight of, were at length established by unequivocal experiments by Dr. Wollaston, since which time a new impulse has been given to this department of Optics; and the successive labours of Laplace, Malus, Brewster, Biot, Arago, and Fresnel present a picture of emulous and successful research, than which nothing prouder has adorned the annals of physical science since the developement of the true system of the universe. To enter, however, into the history of these discoveries, or to assign the share of honour which each illustrious labourer has reaped in this ample field forms no part of our plan. Of the splendid constellation of great names just enumerated, we admire the living and revere the dead far too warmly and too deeply to suffer us to sit in judgment on their respective claims to priority in this or that particular discovery; to balance the mathematical skill of one against the experimental dexterity of another, or the philosophical acumen of a third. So long as "one star differs from another in glory,"—so long as there shall exist varieties, or even incompatibilities of excellence,—so long will the admiration of mankind be found sufficient for all who truly merit it. Waving, then, all reference to the history of the subject, except in the way of incidental remark, or where the necessity of the case renders it unavoidable, we shall present the reader with as systematic an account as we are able, of the present state of knowledge with respect to the laws and theory of Double Refraction. The Huygenian law having been demonstrated to apply rigorously to the case for which he himself devised it, as well as to a very large class of other bodies, we shall begin with that class, and proceed afterwards to consider more complicated cases.

781. Axes of double refraction. In all crystallized bodies, then, which possess double refraction, it is found that that portion of a ray of ordinary light incident on any natural or artificially polished surface which enters the body is separated into *two equal pencils* which pursue rectilinear paths, making with each other an angle not of constant magnitude, but varying according to the position which the incident ray holds with respect to the surface, and to certain fixed lines, or axes within the crystal, and which lines are related in an invariable manner to the planes of cleavage, or other fixed planes or lines in the primitive form of the crystal. Now, it is found that in every crystal there is at least one such fixed line, along which if one of these two pencils be transmitted the other is so also, so that in this case the two pencils coincide, the angle between them vanishing. Moreover, no crystal has yet been discovered in which more than two such lines exist. These lines are called the optic axes. All double refracting crystals, then, at present, may be divided into such as have one, and such as have two, optic axes.

782. Rays moving along the axes suffer ordinary refraction only. When a ray penetrates the surface of a crystal so as to be transmitted undivided along the optic axis; or when, moving within the crystal along that line, it meets the surface and passes out, whatever be the inclination of the surface, its refraction is always performed according to the ordinary law of the proportional sines. Thus, in this particular case, the crystal acts precisely as an uncrystallized medium, (some rare instances excepted, of which more hereafter.)

783. What is meant by axes and fixed lines within a crystal. But in all other cases the law is essentially different, and (for one portion of the divided pencil, at least) of a very singular and complicated nature. This we shall first proceed to explain in the simpler case of crystals with one optic axis. But, first, we must explain somewhat more distinctly, what we mean by axes and fixed lines within a crystal. Suppose a mass of brickwork, or masonry, of great magnitude, built of bricks, all laid parallel to each other. Its exterior form may be what we please; a cube, a pyramid, or any other figure. We may cut it (when hardened into a compact mass) into any shape, a sphere, a cone, or cylinder, &c.; but the edges of the bricks within it lie still parallel to each other; and their directions, as well as those of the diagonals of their surfaces, or of their solid figures, may all be regarded as so many axes, *i. e.* lines having (so long as the mass remains at rest) a determinate position, or rather *direction* in space, no way related to the exterior surfaces, or linear boundaries of the mass, which may cut across the edges of the bricks in any angles we please. Whenever, then, we speak of fixed lines, or axes *of*, or *within*, a crystal, we always mean directions in space parallel to each of a system of lines drawn in the several elementary molecules of the crystal, according to given geometrical laws, and related in a given manner to the sides and angles of the molecules themselves. We must conceive the axis, then, of a crystallized mass not as a single line having a given *place*, but as any line whatever having a given *direction* in space, *i. e.* parallel to the *axis of each molecule*, which is a line having a determinate place and position within it.

784. In the remainder of this section, when we speak of the *axis* or *axes* of a crystallized mass or surface generally, we mean the direction of the optic axis or axes of its molecules, or of a crystal similar and similarly situated to any one of them.

Of the Law of Double Refraction in Crystals with One Optic Axis.

785. Enumeration of crystals having a single axis in classes. This class of crystals comprises all such as belong to Mohs's rhombohedral system, or which have the acute or obtuse rhomboid, or regular six-sided prism, for their primitive form, as well as all which belong to his pyramidal system, or whose primitive form is either the octohedron with a square base, the right prism with a square base, or the bi-pyramidal dodecahedron. All such crystals Dr. Brewster has shown to have but one axis, which is that to which the primitive form is symmetrical, *viz.* in the rhomboid, the axis of the figure, or line joining the two angles formed by three equal plane angles; in the hexagonal prism, the geometrical axis of the prism; in the octohedron, or square based prism, a line drawn through the centre of the base at right angles to it. The cases in accordance with the rule are so numerous, and the exceptions, once believed to be so, have so often disappeared on the attainment of a more perfect knowledge of the crystalline forms of the excepted minerals, that when any case of disagreement seems to occur, we are justified in attributing it rather to our own incorrect determination of this datum, than to want of generality in the rule itself.

786. Refraction of the ordinary ray in this class of crystals. In all crystals of this class, one of the two equal pencils into which the refracted ray is divided follows the ordinary law of Snellius and Descartes, having a constant index of refraction (μ), or invariable ratio of the sine of incidence to that of refraction, whatever be the inclination of the surface by which it enters; so that its velocity within the medium, when once entered, is the same in whatever direction it traverses the molecules; and with respect to this ray the crystal comports itself as an uncrystallized medium. This, then, is called the *ordinary* pencil.

787. Huygens's law for the velocity of the extraordinary ray. To understand the law obeyed by the other, or *extraordinary* portion of the divided pencil, let us consider it as fairly immersed in the medium, and pursuing its course among the molecules. Then its velocity will not, as in the case of the ordinary ray, be the same in whatever direction it traverses them, but will depend on the angle it makes with the axis; being a minimum when its path within the crystal is parallel to the axis, and a maximum when at right angles to it, or *vice versâ;* and in all intermediate inclinations of an intermediate magnitude according to the following law. Let an ellipsoid of revolution, either oblate or prolate, as the case

may be, be conceived, having its axis of revolution coincident in direction with the axis of the crystal, and its polar to its equatorial radius in the ratio of the minimum and maximum velocities above mentioned, *i. e.* as the velocity of a ray moving parallel to that of one perpendicular to the axis. Then in all intermediate positions, the radius of this spheroid parallel to the ray will represent its velocity on the same scale that its polar and equatorial radii represent the velocities in their respective directions.

788. Its connection with the law of extraordinary refraction.

This is the Huygenian law of velocities, in its most simple and general form. It does not at first sight appear what this has to do with the law of extraordinary refraction; but the reader who has considered with the requisite attention what has been said in Art. 539, 540, with prospective reference to this very case, will easily perceive that, the law of velocity of the ray within the medium once established, it becomes a mere matter of pure Geometry to deduce from it the law of extraordinary refraction, whether we adopt the Corpuscular theory, and employ Laplace's principle of least action, as in that Article; or whether, preferring the Undulatory hypothesis, we substitute for this principle the equivalent one of swiftest propagation, as explained in Art. 587, 588. We should observe, however, that the Huygenian law, as just stated, is worded in conformity with the undulatory doctrine, in which the velocity in a denser medium is supposed *slower* than in a rarer. But when we use the principle of least action, we must invert the use of the word, or, which comes to the same thing, suppose the the velocity in the medium to be *inversely* proportional to the radius of the ellipsoid. The results being necessarily the same in both cases, we shall use at present the language of the Corpuscular system.

789. Investigation of the latter from the former law.

Retaining, then, the notation of Art. 540, the law of refraction will be derived from the equation $V . S + V' . S'$ = a minimum, where V is the velocity *without*, and V' that *within* the medium, and where S and S' are the spaces described without and within it, in the passage of a ray from point to point. Let a and b be the polar and equatorial semiaxes of the ellipsoid above spoken of, (which we shall call the ellipsoid of double refraction,) and let α, β, γ be the coordinates of the point (A) without the crystal, and α', β', γ' those of one (B) within it, through which the ray is supposed to pass, and x, y, z the coordinates of a point in the surface of the crystal, on which it must be incident, so as to be capable of passing from A to B in the manner required by the law of extraordinary refraction; and let ϕ be the angle which the interior portion S' makes with the axis of the crystal.

Expression for the radius of the spheroid of refraction.

Then will the radius of the spheroid parallel to this portion (by conic sections) be expressed by

$$r = \frac{a\,b}{\sqrt{b^2 . \sin\phi^2 + a^2 \cos\phi^2}} = \frac{a\,b}{W}; \quad (1)$$

where a is the equatorial, and b the polar radius of the spheroid. Now, if we take μ to represent the index of ordinary refraction, since we have, generally, $V' = \frac{\text{const}}{r}$, and since, when $r = b$ the extraordinary and ordinary rays coincide, and therefore $V' = \mu V$, consequently we must have $\mu V = \frac{\text{const}}{b}$, and const $= b \mu V$, so that we shall get

$$V' = \mu V . \frac{b}{r}, \text{ and } \frac{V'}{V} = \mu . \frac{b}{r}.$$

790. Introduction of the principle of least action or swiftest propagation. Fig. 169.

In general, as we have already seen, the condition of least action affords the equation

$$d\{V S + V' S'\} = 0, \text{ or } V . dS + V' . dS' + S' . dV' = 0; \quad (2)$$

But to make use of this, we must express V', S, and S', in terms of variable quantities relating to a point any how taken in the surface of the crystal. Whether this point be expressed by rectangular or polar coordinates is no matter: it will be more convenient, however, to use polar. Let, then, C (fig. 169) be the point of incidence of the ray A C on the surface H a O b, and about C as a centre describe a sphere. Let Z C z be the perpendicular to the surface at C, and let P C p be the position of the axis of the crystal. The plane Z P H z p O Z perpendicular to the surface, and passing through the axis, is called the principal section of the surface. Let Z A a, z B b be vertical planes, containing the incident and refracted rays, and join B p by the arc of a great circle. Then it is evident, that this arc will be equal to ϕ.

791. Suppose, now, the axis of the x to be parallel to H C the projection of the axis of the crystal, and since we may choose the plane of the x, y, as we please, let it coincide with the refracting surface, so that $z = 0$. Then dropping the perpendiculars A M, M m, B N, N n, and putting λ = Z P = z p = angle between the axis and perpendiculars.

ϖ = O a = inclination of the plane of incidence to the principal section.
ϖ' = O b = inclination of plane of refraction to ditto.
θ = angle Z C A = Z A = angle of incidence
θ' = z C B = z B = angle of refraction.

We shall have as follows:

$$AC = S;\ AM = \gamma;\ Cm^2 = (\alpha - x)^2;\ Mm^2 = (\beta - y)^2;$$

consequently,

$$\left.\begin{array}{l} \alpha - x = \gamma . \tan\theta . \cos\varpi;\ \beta - y = \gamma . \tan\theta . \sin\varpi;\ S = \dfrac{\gamma}{\cos\theta} \\ \text{and, similarly,} \\ \alpha' - x = \gamma' . \tan\theta' . \cos\varpi';\ \beta' - y = \gamma' . \tan\theta' . \sin\varpi';\ S' = \dfrac{\gamma'}{\cos\theta'} \end{array}\right\} \quad (3)$$

Now, differentiating these equations, and considering that $d(\alpha - x) = d(\alpha' - x)$ and $d(\beta - y) = d(\beta' - y)$ we get

$$d(\tan\theta \,.\, \cos\varpi) = \frac{\gamma'}{\gamma} \,.\, d(\tan\theta' \,.\, \cos\varpi');$$

$$d(\tan\theta \,.\, \sin\varpi) = \frac{\gamma'}{\gamma} \,.\, d(\tan\theta' \,.\, \sin\varpi');$$

which equations, developed and reduced, afford the following,

$$\left.\begin{aligned} \frac{d\theta}{d\theta'} &= \frac{\gamma'}{\gamma} \,.\left(\frac{\cos\theta}{\cos\theta'}\right)^2 . \cos(\varpi - \varpi'); \quad \frac{d\theta}{d\varpi'} = \frac{\gamma'}{\gamma} \,.\, \cos\theta^2 \,.\, \tan\theta' \,.\, \sin(\varpi - \varpi'); \\ \frac{d\varpi}{d\theta'} &= \frac{\gamma'}{\gamma} \,.\, \frac{\sin(\varpi' - \varpi)}{\tan\theta \,.\, \cos\theta'^2}; \qquad\qquad \frac{d\varpi}{d\varpi'} = \frac{\gamma'}{\gamma} \,.\, \frac{\tan\theta'}{\tan\theta} \cos(\varpi' - \varpi); \end{aligned}\right\} \quad (4)$$

which are necessary conditions, in order that the point C may remain on the surface.

But since S, S′, V′ may be regarded as functions of θ' and ϖ', which are the polar coordinates we propose to use as independent variables, we shall have 792.

$$d\,V' = \frac{d\,V'}{d\theta'} d\theta' + \frac{d\,V'}{d\varpi'} d\varpi';$$

and, moreover,

$$d\,S = \frac{\gamma \,.\, \sin\theta}{\cos\theta^2}\left(\frac{d\theta}{d\theta'} d\theta' + \frac{d\theta}{d\varpi'} d\varpi'\right) d\,S' = \frac{\gamma' \,.\, \sin\theta'}{\cos\theta'^2} d\theta',$$

so that, substituting their values in the equation (2,) we get

$$\begin{aligned} 0 = &\left\{V \,.\, \frac{\gamma \,.\, \sin\theta}{\cos\theta^2} \,.\, \frac{d\theta}{d\theta'} + V' \,.\, \frac{\gamma' \,.\, \sin\theta'}{\cos\theta'^2} + \frac{\gamma'}{\cos\theta'} \,.\, \frac{d\,V'}{d\theta'}\right\} d\theta' \\ &+ \left\{V \,.\, \frac{\gamma \,.\, \sin\theta}{\cos\theta^2} \,.\, \frac{d\theta}{d\varpi'} + \frac{\gamma'}{\cos\theta'} \,.\, \frac{d\,V'}{d\varpi'}\right\} d\varpi'; \end{aligned} \quad (5)$$

in which the coefficients of each of the two independent differentials being separately made to vanish, we get

$$\left.\begin{aligned} \frac{d\,V'}{d\theta'} &= -V \,.\, \frac{\gamma}{\gamma'} \,.\, \frac{\sin\theta \,.\, \cos\theta'}{\cos\theta^2} \,.\, \frac{d\theta}{d\theta'} - V' \,.\, \tan\theta' \\ \frac{d\,V'}{d\varpi'} &= -V \,.\, \frac{\gamma}{\gamma'} \,.\, \frac{\sin\theta \,.\, \cos\theta'}{\cos\theta^2} \,.\, \frac{d\theta}{d\varpi'} \end{aligned}\right\}. \quad (6)$$

In these, substituting the values of $\frac{d\theta}{d\theta'}$ and $\frac{d\theta}{d\varpi'}$ found in equation (4,) we obtain the following

$$\left.\begin{aligned} \frac{d\,V'}{d\theta'} &= -V \,.\, \frac{\sin\theta}{\cos\theta'} \,.\, \cos(\varpi - \varpi') - V' \,.\, \tan\theta' \\ \frac{d\,V'}{d\varpi'} &= -V \,.\, \sin\theta \,.\, \sin\theta' \,.\, \sin(\varpi - \varpi') \end{aligned}\right\}; \quad (7)$$

These are the very same equations with those deduced by Laplace and Malus, by a more abstruse and complicated calculus, from the primary dynamical relations of the problem, and from them it is easy to express, in general, the law of refraction corresponding to any given law of velocities, for we have only to put them under the form

$$V \,.\, \sin\theta \,.\, \cos\varpi \,.\, \cos\varpi' + V \,.\, \sin\theta \,.\, \sin\varpi \,.\, \sin\varpi' = -V' \,.\, \sin\theta' - \cos\theta' \,.\, \frac{d\,V'}{d\theta'}$$

$$V \,.\, \sin\theta \,.\, \cos\varpi \,.\, \sin\varpi' - V \,.\, \sin\theta \,.\, \sin\varpi \,.\, \cos\varpi' = \frac{1}{\sin\theta'} \frac{d\,V'}{d\varpi'};$$

and multiplying the first by $\cos\varpi'$, and the second by $\sin\varpi'$, and adding, we get

$$V \,.\, \sin\theta \,.\, \cos\varpi = \frac{\sin\varpi'}{\sin\theta'} \,.\, \frac{d\,V'}{d\varpi'} - \cos\theta' \,.\, \cos\varpi' \,.\, \frac{d\,V'}{d\theta'} - \sin\theta' \,.\, \cos\varpi' \,.\, V'; \quad (8)$$

and, again, multiplying the first by $\sin\varpi'$, and the second by $-\cos\varpi'$, and adding, we find

$$V \,.\, \sin\theta \,.\, \sin\varpi = -\frac{\cos\varpi'}{\sin\theta'} \frac{d\,V'}{d\varpi'} - \cos\theta' \,.\, \sin\varpi' \,.\, \frac{d\,V'}{d\theta'} - \sin\theta' \,.\, \sin\varpi' \,.\, V'; \quad (9)$$

Light. Now, the second members of these equations, (when V' the velocity of the extraordinary ray is any function of ϕ the angle it makes with the axis, or of its position within the crystal,) is always explicitly given in terms of θ' and ϖ', so that, calling P and Q their values so expressed, we have at once

$$\tan\varpi = \frac{Q}{P}\,;\ \cos\varpi = \frac{P}{\sqrt{P^2+Q^2}}\,;\ \sin\theta = \sqrt{P^2+Q^2}\,;$$

so that ϖ and θ are directly expressed in terms of ϖ' and θ'; and, therefore, the direction in which a ray, moving anyhow within the crystal will emerge, is known, and *vice versâ*.

793. It only remains to execute these processes in the case before us. To this end (for simplicity) we shall put $V = 1$, and suppose (since a and b, the semiaxes of the spheroid, are arbitrary) $b = \frac{1}{\mu}$, or $\mu = \frac{1}{b}$, and put W for the radical $\sqrt{a^2 . \cos\phi^2 + b^2 . \sin\phi^2}$, when we shall have

$$V' = \frac{W}{a\,b}\,;\ d\,V' = \frac{a^2 - b^2}{a\,b} . \frac{\cos\phi}{W} . d\,(\cos\phi).$$

Now in the spherical triangle Z B p we have, the side $Z\,p = \lambda$; $Z\,B = \theta'$, angle $p\,Z\,B = \varpi'$, and side $p\,B = \phi$, therefore, by spherical trigonometry,

$$\cos\phi = \cos\lambda . \cos\theta' + \sin\lambda . \sin\theta' . \cos\varpi', \qquad (10)$$

and differentiating separately with respect to θ' and ϖ',

$$\frac{d . \cos\phi}{d\,\theta'} = -\cos\lambda . \sin\theta' + \sin\lambda . \cos\theta' . \cos\varpi'$$

$$\frac{d . \cos\phi}{d\,\varpi'} = -\sin\lambda . \sin\theta' . \sin\varpi'.$$

If, then, we write these values in the partial differences of V' in the equations (8) and (9,) they will become

$$\sin\theta . \cos\varpi = -\frac{1}{a\,b\,W}\left\{W^2 . \sin\theta' . \cos\varpi' + (a^2 - b^2)\cos\phi\,[\sin\lambda\,(1 - \cos\varpi'^2 . \sin\theta'^2) - \cos\lambda . \sin\theta' . \cos\theta' . \cos\varpi']\right\}$$

$$\sin\theta . \sin\varpi = -\frac{1}{a\,b\,W}\left\{W^2 . \sin\theta' . \sin\varpi' - (a^2 - b^2)\cos\phi\,[\sin\lambda . \sin\varpi' . \cos\varpi' . \sin\theta'^2 + \cos\lambda . \sin\theta' . \cos\theta' . \sin\varpi']\right\}.$$

In these, let $b^2 + (a^2 - b^2)\cos\phi^2$ be put for W^2, and, bearing in mind that the value of $\cos\phi$ is as given in the equation (10,) we shall see that they will reduce themselves respectively to

$$\sin\theta . \cos\varpi = -\frac{1}{a\,b\,W}\left\{b^2 . \sin\theta' . \cos\varpi' + (a^2 - b^2) . \sin\lambda . \cos\phi\right\}$$

that is, by reason of (10,)

$$\left.\begin{aligned} -\sin\theta . \cos\varpi &= \frac{(a^2 - b^2) . \cos\lambda . \sin\lambda . \cos\theta' + (a^2 . \sin\lambda^2 + b^2 . \cos\lambda^2) . \cos\varpi' . \sin\theta'}{a\,b\,W} \\ \text{and} \\ -\sin\theta . \sin\varpi &= \frac{b^2 . \sin\theta' . \sin\varpi'}{a\,b\,W} \end{aligned}\right\}. \qquad (11)$$

794. These equations, conjointly with the equations expressing the value of W in terms of $\cos\phi$, and of $\cos\phi$ in terms of θ' and ϖ', afford a complete solution of the problem in the case when a ray passes out of a crystal into air, and suffice to determine both the inclination of the refracted ray to the surface, and the inclination of the plane in which it lies to the principal section.

For brevity, let us put

$$a^2 . \sin\lambda^2 + b^2 . \cos\lambda^2 = A;\quad a^2 . \cos\lambda^2 + b^2 . \sin\lambda^2 = B;\quad (a^2 - b^2) . \sin\lambda . \cos\lambda = C; \qquad (12)$$

and, dividing the second of the equations (11) by the first, we find

$$\tan\varpi = \frac{b^2 . \tan\theta' . \sin\varpi'}{A . \tan\theta' . \cos\varpi' + C} \qquad (13)$$

which gives immediately the inclination of the plane of emergence to the principal section, or, as it is sometimes termed, the *azimuth* of the emergent ray.

798. 2d. When the axis lies in the surface.

Case 2. When the axis lies in the surface, or $\lambda = 90^\circ$; $A = a^2$; $B = b^2$; $C = 0$, and the equations become

$$\tan\theta' . \sin\varpi' = \frac{a . \sin\theta . \sin\varpi}{\sqrt{1 - \sin\theta^2 \{ a^2 . \sin\varpi^2 + b^2 . \cos\varpi^2 \}}}; \qquad (18)$$

$$\tan\theta' . \cos\varpi' = \frac{b^2}{a} . \frac{\sin\theta . \cos\varpi}{\sqrt{1 - \sin\theta^2 \{ a^2 . \sin\varpi^2 + b^2 . \cos\varpi^2 \}}}; \qquad (19)$$

$$\tan\varpi' = \frac{a^2}{b^2} . \tan\varpi = \left(\frac{\mu}{\mu'}\right)^2 . \tan\varpi . \qquad (20)$$

The latter of these equations shows that the extraordinary ray deviates from the plane of incidence. The amount of this deviation is nothing when the plane of incidence coincides with the principal section, but increases on either side of it till it attains a certain magnitude, the deviation being *from* the axis, or the plane of refraction making a greater angle with the axis than that of incidence. The two planes then approach each other, and when $\varpi = 90^\circ$, $\tan\varpi = \infty$, $\tan\varpi' = \infty$, and, consequently, $\varpi' = 90^\circ$, or the plane of refraction coincides with that of incidence.

799. Case of refraction in the principal section.

The equations (18) and (19) show that in the present case, the refracted ray does not describe a conical surface about the perpendicular when the incident one does so, and therefore that the law of refraction varies in every different azimuth. Two cases deserve express notice, *viz.* those in which the plane of incidence is coincident with the principal section, and when perpendicular to it. In the former, $\varpi = 0$ and $\varpi' = 0$, so that we have

$$\tan\theta' = \frac{b^2}{a} . \frac{\sin\theta}{\sqrt{1 - b^2 . \sin\theta^2}}. \qquad (21)$$

A remarkable relation holds good in this case between the angles of refraction of the ordinary and extraordinary ray, their tangents being to each other in a given ratio. In fact, if we find $(\theta') =$ the angle of refraction for the ordinary ray, we have $\sin(\theta') = \frac{1}{\mu} . \sin\theta = b . \sin\theta$, and, consequently,

$$\tan\theta' = \frac{b}{a} . \frac{\sin(\theta')}{\sqrt{1 - \sin(\theta')^2}} = \frac{b}{a} . \tan(\theta'). \qquad (22)$$

In the latter case, when the plane of refraction is at right angles to the axis, $\varpi = \varpi' = 90^\circ$, and we get

$$\tan\theta' = \frac{a . \sin\theta}{\sqrt{1 - a^2 . \sin\theta^2}}; \quad \sin\theta' = a . \sin\theta. \qquad (23)$$

800. Case of refraction at right angles to the principal section.

In this case, therefore, the sine of incidence is in a given ratio to that of refraction, and the extraordinary refraction is performed according to the same law as the ordinary, only with a different index, *viz.* μ', or $\frac{1}{a}$, instead of μ, or $\frac{1}{b}$. Hence, if we consider only this particular case, the medium will appear to have two indices of refraction, an ordinary and an extraordinary one.

801. Experimental method of determining the spheroid of double refraction.

It was by a careful examination of these cases, that Dr. Wollaston was enabled to verify the Huygenian law. The circumstance last mentioned puts it in our power to determine in the case of any particular crystal the axes of its spheroid of double refraction. We have only to cut a prism of it, having its refracting angle parallel to the axis, and ascertain its indices of refraction according to the principles laid down in the former part of this Essay, and calling them μ and μ', the semiaxes of the spheroid will be respectively $\frac{1}{\mu}$ and $\frac{1}{\mu'}$. Thus, in the instance of carbonate of lime, which Malus examined with the utmost care, he found the two values of a and b to be respectively equal to the numbers 0.67417 and 0.60449, having determined $\mu' = 1.4833$, and $\mu = 1.6543$. (*Théorie de la Double Réfraction*, p. 199.)

802. In this arrangement, however, it is not possible to decide simply from the phenomena of refraction, which is the ordinary, and which the extraordinary ray. There are, however, infallible and easy criteria, as we shall speedily show. Meanwhile, we may for the present content ourselves with observing, that as a moderate deviation from the exact azimuth $\varpi = 90^\circ$ imparts to the extraordinary ray a deviation from the plane of incidence which does not happen to the ordinary one, this may serve for a criterion to distinguish them in certain cases.

803. Law of the increment of velocity.

The square of the velocity of the ordinary ray within the medium is $\mu^2 V^2$, or μ^2, that is, $\frac{1}{b^2}$, and is constant. That of the extraordinary is V'^2, or $\frac{W^2}{a^2 b^2}$, that is to say, $\frac{\cos\phi^2}{b^2} + \frac{\sin\phi^2}{a^2}$,

or,

$$V'^2 = \frac{1}{b^2} - \left(\frac{1}{b^2} - \frac{1}{a^2}\right) . \sin\phi^2.$$

The square of the velocity of the extraordinary ray is therefore (in the corpuscular doctrine) diminished by a quantity proportional to the square of the sine of the inclination of the ray within the crystal, to the axis. We say diminished, in the algebraical sense of the word, supposing $a > b$, this agrees with common parlance; but if $a < b$, then it will be increased. This gives rise to the subdivision of the crystallized bodies now treated of into two classes, which have by some been termed attractive and repulsive: by others, positive and negative, which seems preferable, as the former phrases involve theoretical considerations. *Positive* crystals are, then, such as have a less than b, or in which the spheroid of double refraction is *prolate*. In these the coefficient $-\left(\frac{1}{b^2} - \frac{1}{a^2}\right)$ which we call k is positive, and the square of the velocity, or $v^2 + k \, . \, \sin \theta^2$, (where $v = \frac{1}{b}$ = velocity of the ordinary ray within the medium,) is increased by the action of the medium, and is a minimum in the axis. In the negative class the coefficient k is negative, $a > b$, or the spheroid of double refraction is *oblate*, and the velocity of the extraordinary ray is a maximum along the axis. In positive crystals, therefore, the index of ordinary refraction (μ) is *less* than that of extraordinary; in negative, greater. To the former class belong quartz, ice, zircon, apophyllite, (when uniaxal;) and to the latter, Iceland spar, tourmaline, beryl, emerald, apatite, &c. The negative class, as far as our present knowledge extends, far out-numbers the positive among natural and artificial crystals. They were first distinguished by M. Biot.

Division of crystals into positive and negative.

804. Undulations propagated in spheroidal surfaces.

In the undulatory doctrine the velocity is the reciprocal of what it is in the corpuscular doctrine, and is therefore *directly* as the radius of the spheroid of double refraction. Hence a wave propagated within the crystal from any point will run over in the same time in different directions, distances proportional to the radii of the spheroid parallel to those directions; and therefore at any instant the surface of the whole wave will be itself a spheroid similar to the spheroid of double refraction. This is Huygens's conception of the subject. It requires us to regard the crystal, or the ether within the crystal through which the undulation is propagated, as having different elasticities in different directions. As far as regards the molecules of a solid body there is no apparent impossibility or improbability in such an idea, but the contrary; but if we regard the propagation of the light within the medium to take place by the elasticity of the ether only, we must then suppose *its* molecules in crystallized bodies to be in a very different physical state from what they are in free space, and either to be in some manner connected with the solid particles, (forming atmospheres, for instance, about them,) or as subjected to laws of mutual action which approximate to those governing the molecules of solid bodies; and partaking, themselves, of a regular crystalline arrangement and mutual dependency.

805. Malus's further researches.

To pursue the particular applications of the general formulæ (13,) 14,) and (15) farther, would be far beyond our limits. The reader who is curious on this very interesting part of Physical Optics, and who wishes to be delighted and instructed by a combination of consummate mathematical skill with sound experimental research, which may deservedly be cited as a model of the kind, will find every thing which relates to the subject in its best form in the work, already so often cited, of Malus, *Théorie de la Double Réfraction*, which gained the mathematical prize of the French Institute in 1810. To the theory of the internal reflexion of the extraordinary ray which offers many remarkable particularities, as there delivered, we must especially refer him, as well as to his investigation of the foci of lenses formed of doubly refracting crystals, of which we shall here only extract the results, in the single case of a double convex lens having the axis of double refraction in the direction of the axis of the lens.

Foci of a doubly refracting lens.

Let r, r' be the radii of the anterior and posterior surfaces of the lens, both supposed convex.
d = distance of the radiant point in the axis.
a, b = the equatorial and polar radii of the spheroid of double refraction, as above.
D = distance of the conjugate focus behind the lens for extraordinary rays.
Δ = extraordinary focal length for parallel rays.
F = ordinary focal length for parallel rays.

Then shall we have for the general expression of D,

$$\mathrm{D} = -\frac{a^2\,b\,d\,r\,r'}{d\,(r + r')\,(2\,b^2 - a^2 - a^2\,b) - a^2\,b\,r\,r'}; \qquad \mathrm{F} = \frac{-\,b\,r\,r'}{(r + r')\,(1 - b)}.$$

If the lens be equi-convex, or $r = r'$,

$$\mathrm{D} = -\frac{a^2\,b\,r\,d}{2\,(2\,b^2 - a^2 - a^2\,b)\,d - a^2\,b\,r}; \qquad \Delta = -\frac{a^2\,b\,r}{2\,(2\,b^2 - a^2 - a^2\,b)};$$

$$\mathrm{F} = -\frac{b\,r}{2\,(1 - b)}; \qquad \Delta - \mathrm{F} = -\,2\,\mathrm{F}\,.\,\frac{a^2 - b^2}{2\,b^2 - a^2 - a^2\,b}.$$

In the case of Iceland spar, these last equations become

$$\mathrm{D} = -\,r\,.\,88{,}2286; \qquad \mathrm{F} = -\,r\,.\,0{,}7642; \qquad \mathrm{D} - \mathrm{F} = -\,\mathrm{F}\,.\,114{,}4546;$$

and in the case of rock crystal (quartz)

$$\mathrm{D} = -\,r\,.\,0.9628; \qquad \mathrm{F} = -\,r\,.\,0{,}8958; \qquad \mathrm{D} - \mathrm{F} = -\,\mathrm{F}.0{,}0748.$$

806. To represent, in general, the course of any extraordinarily refracted ray, Huygens has giving the following construction, (fig. 170.) Let H E D be the elliptic section of the spheroid of double refraction by the surface, and R C the incident ray falling on C its centre, and B C K the orthographic projection of the ray R C on the

Huygens's construction for extraordinary refraction. Fig. 170.

surface. Let H M E be the portion of the spheroid within the crystal, whose axis passes through C, and may be anyhow inclined to the surface. Then will the surface of this spheroid be the boundary of the wave propagated from C as a centre, after the lapse of a given time. Draw C O in the plane R C K at right angles to R C, and make O K (perpendicular to C K, or parallel to R C) equal to the space described by light in the medium exterior to the crystal in the same given time. This will determine the point K in the line B C K. Through K draw K T perpendicular to B K, and about K T as an axis let a plane revolve passing through K T, till it touches the surface of the spheroid in I. Join C I, and C I is the extraordinary refracted ray.

807. Demonstration from the principle of spheroidal undulations.

The demonstration of this construction (granting the principle of spheroidal undulations) is evident, if we consider the manner in which the general wave, a perpendicular to whose surface forms what we term a ray of light, (at least in singly refracting media,) arises from the reunion of all the elementary waves propagated from every part of the surface, (Art. 586.) In this construction, if we conceive a plane wave from an infinitely distant luminary perpendicular to R C to move along R C, every point in the line C K will become *in succession*, and every point in the line C D perpendicular to C K, or parallel to K T *simultaneously*, a centre of vibration. The general wave, therefore, will be a surface touching all ellipsoids described about each point of the surface, having their axes parallel, their generating ellipses similar, and their linear dimensions proportional to the distance of their centre from the line K T. Of course it can be no other than the tangent plane I K T drawn as above.

808. This then will be the form and position of the general wave within the crystal. Now if we consider only that very minute portion of it which emanates from C, it is evident that I is the corresponding point in it; and therefore C I is necessarily the direction of the ray, because I is the point on which that portion of the general wave transmitted through a very small aperture at C would fall.

809. Oblique propagation of the extraordinary ray

Thus we see, that in the case of the extraordinary ray, we are no longer to regard the *ray* as a perpendicular to the surface of the wave. It is propagated obliquely to that surface. So soon, however, as the wave emerges into the ambient medium, the usual law of perpendicular propagation is restored.

810. To show the identity of the law of extraordinary refraction resulting from this construction with that expressed by the general equations (13,) (14,) and (15,) we have only to translate it into analytical language. This has been done by Malus, in his work above referred to; and the reader may also consult Biot's *Traité Général de Physique*, for a more elementary exposition of the process, which is one of considerable complexity, for which reason we shall not embarrass ourselves with it here.

811. Form and position of the extraordinary ray.

Some very remarkable and important consequences follow from this mode of viewing the subject. It appears that when a plane wave is incident on a doubly refracting surface, the transmitted *extraordinary wave* is also plane, and advances with a uniform velocity in a direction oblique to itself. Consequently the velocity is also uniform in a direction perpendicular to itself. Moreover, its common section with the surface is always parallel to K T, or to the common section of the incident wave with the same surface. Hence, it is evident, that it moves in the same way as an ordinarily transmitted wave would do, and at any instant has the same position that such a wave would have, provided the index of refraction in the latter case were properly assumed. The only difference is, that the motions of the vibrating molecules, of which they respectively consist, are executed in different planes. Now, when this wave emerges from the medium, it obeys the same laws as on its entry, only reversed; so that it still continues a plane wave, and its common section with the surface of *emergence* remains unaltered.

812. Consequences in double refraction through prisms.

Hence it follows, that if we cut a prism of any doubly refracting crystal with one axis, and transmit through it a ray incident in a plane at right angles to the edge of the prism, the ordinary and extraordinary ray will both emerge in that plane, and their separation will take place in a plane containing the incident and ordinarily-refracted ray, and will therefore be, apparently, such as would arise from attributing two ordinary refractive powers to the medium. It is only when the edge of the prism is oblique to the plane of incidence, that the extraordinary ray can deviate from the plane containing the incident and ordinarily refracted rays.

813. Velocity of *luminous waves*, and of *rays of light* distinguished. Theory of double refraction in bi-axal crystals deferred, and why.

We see, then, that in the theory of extraordinary refraction, it is necessary to consider, as distinct, two things, which, in that of ordinary, are one and the same, *viz.* the velocity of the *luminous waves*, and the *velocity of the rays of light*. This distinction will require to be very carefully kept in view hereafter, when we come to treat of the law of refraction in crystals with two axes of double refraction. For this, however, we are not yet prepared, as the knowledge of this law presupposes an acquaintance with a multitude of facts relative to the polarization of light, of which we have yet said nothing. It will suffice here to mention, that the whole doctrine of double refraction has recently undergone a great revolution; one, indeed, which may be said to have changed the face of Physical Optics, in consequence of the researches of M. Fresnel. It had all along been taken for granted, that in crystals possessed of double refraction, one of the pencils followed the ordinary law of proportional sines. It had, moreover, been ascertained, by experiments hereafter to be related, that the difference of the squares of the velocities between the two pencils is in all cases proportional to the product of the sines of the angles contained between the extraordinary ray (as it was termed) and the two axes, or directions in which the refraction is single. It was hence concluded, that the velocity of the *extraordinary pencil* was in all cases represented by $\sqrt{v^2 + k \cdot \sin\phi \cdot \sin\phi'}$, v being that of the ordinary one, and k a constant depending on the nature of the crystal, and ϕ, ϕ' the angles in question. This granted, there would be no difficulty in determining the form of the surface of double curvature, which should be substituted for the Huygenian spheroid; so as to render the same construction with that described in Art. 806, or the general formulæ in Art. 792, applicable to this case. In fact, if we call a the semi-angle between the two axes, and conceive three coordinates x, y, z, of which x bisects that angle, the plane of the x, y containing both axes, it is easy to see, by spherical trigonometry, that we must have

$$\cos\phi = \frac{x \,.\, \cos\alpha + y \,.\, \sin\alpha}{\sqrt{x^2+y^2+z^2}}\,; \qquad \cos\phi' = \frac{x \,.\, \cos\alpha - y \,.\, \sin\alpha}{\sqrt{x^2+y^2+z^2}}\,.$$

Hence, since $r\ (\sqrt{x^2+y^2+z^2})$ the radius of the surface of the wave, is always equal to

$$\frac{1}{V'}, \quad \text{or} \quad \frac{1}{\sqrt{v^2 + k^2 \,.\, \sin\phi \,.\, \sin\phi'}}\,,$$

a simple substitution would give at once the equation of its surface as referred to the three coordinates x, y, z; namely,

$$0 = (k^4 - v^4)\,(x^2+y^2+z^2)^2 + 2\,(x^2+y^2+z^2)\,(v^2 - k^2\,x^2 \,.\, \cos\alpha^2 - k^2\,y^2 \,.\, \sin\alpha^2)$$
$$+\ k^4\,(x^2 \,.\, \cos\alpha^2 + y^2 \,.\, \sin\alpha^2)^2 - 1,$$

which it would be easy then to transform into functions of r, ϖ, and θ, as required for the application of the general analytical formulæ by the usual substitutions

$$z = r \,.\, \sin\theta\,; \qquad y = r \,.\, \sin\theta \,.\, \sin\varpi\,; \qquad x = r \,.\, \sin\theta \,.\, \cos\varpi.$$

The researches of M. Fresnel, however, as before remarked, have destroyed the basis on which this theory rested, by demonstrating the non-existence of an ordinarily refracted ray in the case of crystals with two axes. The theory which he has substituted in its place, however, and which it is impossible to regard otherwise than as one of the finest generalizations of modern science, we must reserve for a more advanced place in this essay. We shall now proceed to treat

Of the Polarization of Light.

814. The phenomena which belong to this division of our subject are so singular and various, that to one who has only studied the subject of Physical Optics under the relations presented in the foregoing pages, it is like entering into a new world,—so splendid as to render it one of the most delightful branches of experimental inquiry; and so fertile in the views it lays open of the constitution of natural bodies, and the minuter mechanism of the universe, as to place it in the very first rank of the physico-mathematical sciences, which it maintains, by the rigorous application of geometrical reasoning its nature admits and requires. The intricacy as well as variety of its phenomena, and the unexampled rapidity with which discoveries have succeeded each other in it, have hitherto prevented the possibility of embodying it satisfactorily in a systematic form; but, after the rejection of numberless imperfect generalizations, it seems at length to have acquired that degree of consistency as to enable us—not, indeed, to deduce every phenomenon, by distinct steps, from one general cause—but to present them, at least, in something like a regular succession; to show a mutual dependence between their several classes, which is a main step to a complete generalization; and to dispense with the bewildering detail of an immense multitude of individual facts, which, having served their purpose in the inductive process, must in future be considered as having their interest merged in that of the laws from which they flow.

§ II. *General Ideas of the Distinction between Polarized and Unpolarized Light.*

815. In all the properties and affections of light which we have hitherto considered, we have regarded it as presenting the same phenomena of reflexion and transmission, both as respects the direction and intensity of the reflected or transmitted beam, however it may be presented to the reflecting or refracting surface, provided the angle of incidence, and the plane in which it lies, be not varied. And this is true of light in the state in which it is emitted immediately from the sun, or from other self-luminous sources. A ray of such light, incident at a given angle on a given surface, may be conceived to revolve round an axis coincident with its own direction; or, which comes to the same thing, the reflecting or refracting surface may be actually made to revolve round the ray as an axis, preserving the same relative situation to it in all other respects, and no change in the phenomena will be perceived. For instance, if in a long cylindrical tube we fix a plate of glass, or any other medium at any angle of inclination to the axis; and then, directing the tube to the sun, turn the whole apparatus round on its axis, the intensity of the reflected or refracted ray will suffer no variation, and its direction (if deviated) will revolve uniformly round with the apparatus, so that if received on a screen connected invariably with the tube, it will continue to fall on the very same point in all parts of its rotation. Or we may receive the light from a piece of white hot iron at any angle on any medium, and its phenomena will be precisely the same, whether the iron be at rest, or be made to revolve round an axis coincident with the direction of the ray.

816. But, if instead of employing a ray immediately emitted from a self-luminous source, we subject to the same examination a ray that has undergone some reflexions, refractions, or been in any one of a great variety of ways subjected to the action of material bodies, we find this perfect uniformity of result no longer to hold good. It is no longer indifferent in what plane, with respect to the ray itself, the reflecting or refracting surface is presented to it. It seems to have acquired *sides*; a right and left, a front and back; and the *intensity*, though not the direction of the reflected or transmitted portion, depends materially on the position with respect to these

Polarized rays have acquired fixed relations to external space.

Illustration. sides, in which the plane of incidence lies, though every thing else remains precisely the same. In this state it is said to be polarized. The difference between a polarized and an ordinary ray of light can hardly be more readily conceived than by assimilating the latter to a cylindrical, and the former to a four-sided prismatic rod, such as a lath or a ruler, or other long, flat, straight stick. It is evident that the cylinder, if inclined to any surface at a given angle in a given plane, may be turned round its own axis without altering its relations to the plane, while those of the prism will vary essentially according to the position of its sides. Let us suppose, for instance, (it is but a simile, which we do not wish the reader to dwell on for a moment, or to imagine that any analogy is hereafter intended to be established,) that we had occasion to thrust such a rod into a surface composed of detached fibres, all lying in one direction, or of scales or laminæ arranged parallel to one another, we should find a much greater facility of penetration on presenting its broad side in the direction of the laminæ or fibres, than transverse to them. A thin sheet may be slipped between the bars of a grating, which would present an insuperable obstacle to it if presented cross-wise.

817. Property of the tourmaline and other crystals. But, to be more particular, and to give a more clear conception of the marked distinction which exists between a polarized and an unpolarized ray. There are many crystallized minerals, which when cut into parallel plates are sufficiently transparent, and let pass abundance of light with perfect regularity, but which, nevertheless, at its emergence is found to have acquired that peculiar modification here in question. One of the most remarkable of these is the tourmaline. This mineral crystallizes in long prisms, whose primitive form is the obtuse rhomboid, having its axis parallel to the axis of the prism. The lateral faces of these prisms are frequently so numerous as to give them an approach to a cylindrical or cylindroidal form. Now if we take one of these crystals, and slit it (by the aid of a lapidary's wheel) into plates parallel to the axis of the prism of moderate and uniform thickness, (about $\frac{1}{20}$ of an inch,) which must be well-polished, luminous objects may be seen through them, as through plates of coloured glass. Let one of these plates be interposed perpendicularly between the eye and a candle, the latter will be seen with equal distinctness in every position of the axis of the plate with respect to the horizon, (by the axis of the plate is meant any line in it parallel to the axes of its molecules, or to the axis of the prism from which it was cut.) And if the plate be turned round on its own plane, no change will be perceived in the image of the candle. Now, holding this first plate in a fixed position, (with its axis vertical, for instance,) let a second be interposed between it and the eye, and turned round slowly in its own plane, and a very remarkable phenomenon will be seen. The candle will appear and disappear alternately at every quarter revolution of the plate, passing through all gradations of brightness, from a maximum down to a total, or almost total, evanescence, and then increasing again by the same degrees as it diminished before. If now we attend to the position of the second plate with respect to the first, we shall find that the *maxima* of illumination take place when the axis of the second plate is parallel to that of the first, so that the two plates have either the same positions with respect to each other that they had in the original crystal, or positions differing by 180°, while the mimima, or evanescences of the image, take place exactly 90° from this parallelism, or when the axes of the two plates are exactly crossed. In tourmalines of a good colour, the stoppage of the light in this situation is total, and the combined plate (though composed of elements separately very transparent and of the same colour) is perfectly opake. In others it is only partial; but however the specimens be chosen, a very marked defalcation of light in the crossed position takes place. We shall at present suppose that the specimens employed possess the property in question in its greatest perfection. Now it is evident that the light which has passed through the first plate has acquired in so doing a property totally distinct from those of the original light of the candle. The latter would have penetrated the second plate equally well in all its positions; the former is incapable altogether of penetrating it in some positions, while in others it passes through readily, and these positions correspond to certain *sides* which the ray has acquired, and which are parallel and perpendicular respectively to the axis of the first plate. Moreover, these *sides* once acquired, are retained by the ray in all its future course, (provided it be not again otherwise modified by contact with other bodies,) for it matters not how great the distance between the two plates, whether they be in contact or many inches, yards, or miles asunder, not the least variation is perceived in the phenomenon in question. If the position of the first plate be shifted, the sides of the transmitted ray shift with it, through an equal angle, and the second will no longer extinguish it in the position it at first did, but must be brought into a position removed therefrom, by an angle equal to that through which the first plate has been made to revolve.

818. Selection of proper tourmalines. A great many other crystallized bodies besides the tourmaline possess this curious property, and several in great perfection. The tourmaline, however, is one easily procured, and being exceedingly useful in optical experiments, we would recommend the reader who has any desire to familiarize himself with the practical manipulations of this branch of optical science, to provide himself with a good pair of corresponding plates of this mineral, cut and polished as above directed. The colour is a point of great moment. Those of a blue or green colour possess the property in question very imperfectly; the yellow varieties, unless when verging to greenish brown, are equally improper, the best colour is a hair-brown, or purplish brown, and they may be slit and polished by any lapidary.

819. Various modes of polarizing light. But it is not only by such means that the *polarization* of a pencil of light may be operated, nor is this the only character which distinguishes polarized from ordinary light. We shall, therefore, describe in order, the principal means by which the polarization of light may be performed, and the assemblage of characters which are invariably found to coexist in a ray when polarized.

The chief modes by which the polarization of light may be effected, are

1st. By reflexion at a proper angle from the surfaces of transparent media.

2d. By transmission through a regularly crystallized medium possessed of the property of double refraction.

3d. By transmission through transparent, uncrystallized plates in sufficient number, and at proper angles.

4th. By transmission through a variety of bodies, such as agate, mother-of-pearl, &c. which have an approach to a laminated structure, and an imperfect state of crystallization.

820. Characters of a polarized ray of light. The characters which are invariably found to coexist in a polarized ray, being the chief of those by which it may be most easily recognised as polarized, are—

1. Incapability of being transmitted by a plate of tourmaline, as above described, when incident perpendicularly on it, in certain positions of the plate; and ready transmission in others, at right angles to the former.

2. Incapability of being reflected by polished transparent media at certain angles of incidence, and in certain positions of the plane of incidence.

3. Incapabiltiy of undergoing division into two equal pencils by double refraction, in positions of the doubly refracting bodies, in which a ray of ordinary light would be so divided.

Affect the intensity and not the direction of the ray.

Besides which, there might be enumerated a vast variety of other characters, which, however, it will be better to regard as *properties* at once of polarized light, and of the various media which affect it. It cannot fail to be remarked, that all these characters are of the *negative kind*, and consist in denying to polarized light properties which ordinary light possesses, and that they are such as affect the intensity of the ray, not its direction. Thus, the direction which a polarized ray will take under any circumstances of the action of media, is never *different* from what an unpolarized ray might take, and from what a portion of it at least actually does. For instance, when an unpolarized ray is separated by double refraction into two equal pencils, a polarized ray will be divided into two unequal ones, one of which may even be altogether evanescent, but their directions are precisely the same as those of the pencils into which the unpolarized ray is divided. Hence we may lay it down as a general principie, that the *direction* taken by a polarized ray, or by the parts into which it may be divided by any reflexions, refractions, or other modifying causes, may always be determined by the same rules as apply to unpolarized light; but that the relative *intensities* of these portions differ from those of similar portions of unpolarized light, according to certain laws which it is the business of the optical inquirer to ascertain.

§ III. *Of the Polarization of Light by Reflexion.*

821. Light polarized by reflexion. When a ray of direct solar light is received on a plate of polished glass or other medium, a portion more or less considerable is always reflected. The intensity of this portion depends only on the nature of the medium and on the angle of incidence, being greater as the refractive power of the former is greater, and as the ray falls more obliquely on the surface. But it is, moreover, found, that at a certain angle of incidence, (which is therefore called the *polarizing angle*,) the reflected ray possesses all the characters above enumerated, and is therefore *polarized*.

822. Discovery by Malus. This remarkable fact was discovered by Malus in 1808, when accidently viewing, through a doubly refracting prism, the light of the setting sun reflected from the glass windows of the Luxembourg Palace in Paris. On turning round the prism, he was surprised to observe a remarkable difference in the intensity of the two images; the most refracted alternately surpassing and falling short of the least in brightness, at each quadrant of the revolution. This phenomenon connecting itself in his mind with similar phenomena produced by rays which had undergone double refraction, and with which, from the researches he was then engaged in, he was familiar, led him to investigate the circumstances of the case with all possible attention, and the result was the creation of a new department of Physical Optics. So true it is, that a thousand indications pass daily before our eyes which might lead to the most important conclusions. The seeds of great discoveries are everywhere present and floating around us, but they fall in vain on the unprepared mind, and germinate only where previous inquiry has elaborated the soil for their reception, and awakened the attention to a perception of their value.

823. Experiment. To make this new property acquired by the reflected ray evident by experiment, let any one lay down a large plate of glass on a black cloth, on a table before an open window, and placing himself conveniently so as to look obliquely at it, let him view the reflected light of the sky, (or, which is better, of the clouds if not too dark,) from the whole surface, which will thus appear pretty uniformly bright. Then let him close one eye, and apply before the other a plate of tourmaline, cut as above directed, so as to have *its axis in a vertical plane*. He will then observe the surface of the glass, instead of being as before equally illuminated, to have on it, as it were, an obscure cloud, or a large blot, the middle of which is totally dark. If this be not seen at first, it will come into view on elevating or depressing the eye. If the inclination of a line drawn from the centre of the dark spot to the eye be measured, it will be found to make an angle of about 33° with the surface of the glass. If now, keeping the eye fixed on the spot, the tourmaline plate (which it is convenient to have set in a small circular frame for such experiments) be turned slowly round in its own plane, the spot will grow less and less obscure, and *when the axis of the tourmaline is parallel to the reflecting surface*, (or horizontal,) will have disappeared completely, so as to leave the surface equally illuminated, and, on continuing the rotation of the tourmaline, will appear and vanish alternately.

824 It appears from this experiment, that the ray which has been reflected from the surface of the glass at an inclination of 33°, or an incidence of 57°, has thereby been deprived of its power to penetrate a tourmaline plate whose axis lies in the plane of incidence. It has therefore acquired the same character, or (so far as this goes, at least) undergone the same modification as if, instead of being reflected on glass, it had been transmitted through a tourmaline plate, whose axis was perpendicular to the plane of reflexion.

It has, moreover, acquired all the other enumerated characters of a polarized ray. And, first, it has become incapable of reflexion at the surface of glass, or other transparent media at certain definite angles, and in certain positions of the plane of incidence. To show this experimentally, let a piece of polished glass have one of its surfaces roughened, and blackened with melted pitch or black varnish, so as to destroy its internal reflexion, and let this be fixed on a stand, so as to be capable of varying at will the inclination of its polished surface to the horizon, and of turning it round a vertical axis in any azimuth. A very convenient stand of this kind is figured in fig. 171, consisting of a cylindrical support A sliding in a vertical tube B, attached to a round base F like a candlestick, and carrying an arm C, which can be set to any angle of inclination to the horizon by means of a stiff shoulder joint D. To this arm the blackened glass E is fixed, having its plane parallel to the axis of the joint D. Let this apparatus be set on a table, so that the rays reflected from a pretty large plate of glass G, at an angle of about 57° (of incidence) shall be received on the glass E, which ought to be inclined with its polished surface looking downwards, and making an angle of about 73° with the horizon, see Art. 842. Then let the observer apply his eye near the glass E, so as to see the glass G reflected in it, and slowly turn the stand F round in a horizontal plane, keeping always the reflected image of G in view. He will then perceive, that at a certain point of the rotation of the stand, the illumination of this image, which in other situations is very bright, will undergo a rapid diminution, and at last wholly disappear, and (if the glass G be large enough) the same appearance of a cloud or large dark spot will then be visible upon it. If the inclination of the arm C D be correct, it will be easy to find such a position by turning the stand a little backwards and forwards, as shall make the centre of this spot totally black; if not, bring it to as great a degree of obscurity as possible by the horizontal motion, then, holding fast the stand, vary a little one way or another the inclination of the reflector E, and a very complete obscurity will readily be attained.

825. Experiment. The polarized ray incapable of a second reflexion, &c. Fig. 171.

826. Another mode of making the experiment. Fig. 172.

Another, and, for some experimental purposes, a better way of exhibiting the same phenomenon, is to take two metallic or pasteboard tubes, open at both ends, and fitting into each other so as to turn stiffly. Into each of these, at the end remote from their junction, fix with wax, or in a frame, a plate of glass, blackened at the back as above described, so as to make an angle of 33° with the axis of the tube, as represented in fig. 172. Then having placed the tube containing one of the plates (A) so that the light from any luminary, reflected at the plate shall traverse the axis of the tube, fix it there, and the reflected ray will be again reflected at B, and on its emergence may be received on a screen or on the eye. Now make the tube containing the reflector B revolve within the other, so that that reflector shall revolve round the ray A B as an axis, preserving the same inclination. Then will the twice reflected ray revolve with equal angular motion, and describe a conical surface. But in so doing, it will be observed to vary in intensity, and at two points of the revolution of the tube B will *disappear altogether*. Now if we attend to the position of the reflectors at this moment, it will be found that *the planes of the first and second reflexion make a right angle.*

827. By repeating these experiments with all sorts of reflecting media, and determining by exact measurement the angles at which the original ray must be incident that polarization shall take place, and those at which a polarized ray ceases to be reflected, the following laws have been ascertained to hold good, previous to announcing which a definition will be necessary.

828. Plane of polarization defined.

Definition. The plane of polarization of a polarized ray is the plane in which it must have undergone reflexion, to have acquired its character of polarization; or that plane passing through the course of the ray perpendicular to which it cannot be reflected at the polarizing angle from a transparent medium; or, again, that plane in which, if the axis of a tourmaline plate exposed perpendicularly to the ray be situated, no portion of the ray will be transmitted. Also, a polarized ray is said *to be polarized in* its plane of polarization, as just defined.

829. Sides of a polarized ray.

The plane of polarization of any polarized ray is to be considered as one of the *sides* of the ray which thus, in all its future progress, carries with it certain relations to surrounding fixed space, which must be regarded, while they continue unchanged, as inherent in the ray itself, and as having no further any relation to the particular mode in which they originated.

830. Laws of polarization by reflexion. Law 1.

The laws of polarization by reflexion are these:

Law 1. All reflecting surfaces are capable of polarizing light if incident at proper angles; only, metallic bodies, or bodies of very high refractive powers, appear to do so but imperfectly, the reflected ray not *entirely* disappearing in circumstances when a perfectly polarized ray would be completely extinguished. Of this more hereafter.

831. Law 2. Brewster's law of the tangents.

Law 2. Different media differ in the angles of incidence at which they polarize light; and it is found, that these angles may always be determined from the following simple and elegant relation, discovered by Dr. Brewster after a laborious examination of an infinite variety of substances.

The tangent of the polarizing angle for any medium is the index of refraction belonging to that medium.

Thus, the indices of refraction of water, crown-glass, and diamond, being respectively 1.336, 1.535, and 2.487, their respective polarizing angles will be 53° 11′, 56° 55′, and 68° 6′. For diamond, however, or bodies of very high refractive powers, we must understand by the polarizing angle, that angle of incidence at which the reflected ray approximates most nearly to the character of a ray completely polarized.

832. All the colours not polarized at one incidence.

It follows from this law, that one and the same medium does not polarize all the coloured rays at the same angle, and that therefore the disappearance of the reflected pencil can never be total, except where the incident ray is homogeneous. This will account *in some degree* for the want of complete polarization of a white ray, reflected at any angle from highly refractive media, which are generally also highly dispersive. Of the reality of the fact, it is easy to satisfy oneself by a very simple experiment, which we have often made. Receive a sunbeam on a plane glass, with the back roughened and blackened, at an incidence (θ) nearly equal to the polarizing angle (a,) and let the reflected ray pass into a darkened room, and fall on another similar glass, which may be held in the hand, so as to reflect the ray in a plane at right angles to that of the first reflection, and

Proved by experiment.

also at an angle (θ') nearly equal to the polarizing angle (a') of the second plate. It will be easy to find a position where the reflected ray (which must be received on a white screen) very nearly vanishes; but no adjustment of the angles of incidence θ and θ' will produce a *total* disappearance. When the disappearance is most nearly total, the reflected light is coloured of a neutral purple; the yellow, or most luminous rays, being now totally extinguished. In this position, if θ remain constant, and θ' the incidence on the second plate be varied a little on one side or the other of the polarizing angle a', the reflected ray assumes on the one hand a pretty intense blue-green, and on the other a ruddy plum colour or amethyst red. The several changes of tint, arising from variations of incidence on both plates, were observed to be as follows:

1st.	$\theta < a$;	$\theta' < a'$;	Reflected ray, Strong green.
		Intermediate,	———— White.
		$\theta' > a'$;	———— Pale red or amethyst.
2d.	$\theta = a$;	$\theta' < a'$;	———— Strong blue green.
		$\theta' = a'$;	———— Neutral purple.
		$\theta' > a'$;	———— Strong plum colour.
3d.	$\theta > a$;	$\theta' < a'$;	———— Light greenish blue.
		Intermediate,	———— White.
		$\theta' > a'$;	———— Strong red, or plum colour.

The rationale of these changes of colour will be more evident when we have announced the following law, which expresses one of the most general and distinguishing characters of polarized light.

833. Law 3. Non-reflexibility of polarized light in certain, and what cases.

Law 3. When a polarized ray (no matter how it acquired its polarization) is incident on a reflecting surface of a transparent, or other medium capable of completely polarizing light, in a plane perpendicular to that of the ray's polarization, and at an angle of incidence equal to the polarizing angle of the medium, no portion of the ray will be reflected. If the medium be of such a nature as to be capable only of incompletely polarizing light, a portion will be reflected, but much less intense than if the incident ray were unpolarized.

It is evident that this property may be employed to distinguish polarized from common light, as well as that of extinction by a plate of tourmaline. It is, however, much less convenient though better adapted for delicate inquiries.

834. Explanation of the colours in the last experiment.

The polarizing angle for white light is, in fact, the angle for the most luminous or mean yellow rays; and when the two reflexions, in planes at right angles to each other, are made at this angle, the yellow rays only totally escape reflexion, but a very small portion both of the red and blue end of the spectrum are reflected, and form a feeble purple beam, such as above described. The polarizing angle for red rays being less than for violet, it is evident that when either θ or θ' is equal to the polarizing angle for red, it will be less than that of yellow, and still less than that of blue and violet rays; thus, the red disappears most completely from the reflected beam in those cases when θ or θ' are less than a or a', leaving an excess of the green and blue rays, and *vice versâ* in the converse cases. Thus, too, if θ be $< a$, and at the same time $\theta' < a$, the colour produced will be a more intense green than if the incidences deviated opposite ways from the polarizing angles; and it is evident, that a compensation may arise from the effect of such opposite deviations giving an intermediate white ray, exactly as we see to have happened.

835. Some very remarkable consequences follow from the law announced by Dr. Brewster for finding the polarizing angle, which may be presented in the form of distinct propositions. Thus,

836. Consequences of the law of polarization.

Prop. 1. When a ray is incident on a transparent surface, so that the reflected portion shall be completely polarized, the reflected and refracted portions make a right angle. For θ being the angle of incidence, we have $\tan \rho = \mu$ and ρ, being the angle of refraction, $\sin \rho = \frac{\sin \theta}{\mu} = \frac{\sin \theta}{\tan \theta} = \cos \theta$. Therefore $\rho = 90° - \theta$, but θ being the angle of incidence is also that of reflexion, and $\rho + \theta$ is therefore equal to the supplement of the angle between the reflected and refracted rays, which is therefore a right angle. Q. E. D.

837. Polarization by internal reflexion.

Prop. 2. When a beam of common light is incident at the polarizing angle on a parallel plate of a transparent medium, not only the portion reflected at the first surface, but also that reflected internally at the second, and the compound reflected ray, consisting of both united, are polarized.

Since $\sin \rho = \cos \theta$, and since ρ is also the angle of incidence on the second surface, we shall have $\tan \rho = \text{cotan}\, \theta = \frac{1}{\tan \theta} = \frac{1}{\mu}$ = index of refraction *out* of the medium. Hence, ρ is the angle of polarization for rays internally incident, and therefore that portion of the beam which, having penetrated the first surface, falls on the second, being incident at its polarizing angle, the portion reflected *here* will also be polarized, and being again incident on the first surface, in the plane of its polarization, that part of it which is transmitted will (as we shall see hereafter) suffer no change in its plane of polarization, so that both it and the first reflected ray will come off polarized in the same plane. Q. E. D.

838. *Corol*. 1. Hence, to obtain a stronger polarized ray, we may dispense with roughening or blackening the posterior surface, provided we are sure that the surfaces are truly parallel.

839. Mode of obtaining an intense polarized beam.

If a series of parallel plates be laid one on the other so as to form a pile, the portions reflected from the several surfaces all come off polarized in the same plane, and by this means a very intense polarized ray may be obtained. It can never, however, for a reason we shall presently state, contain more than half the incident light, whatever be the number of plates employed.

840. For a great variety of optical experiments, a pile consisting of ten or a dozen panes of common window-glass set in a frame, is of great use and very convenient. Such a pile laid down before an open window affords a dispersed beam, each ray of which is polarized at the proper angle, and of great intensity and very proper for the exhibition of many of the phenomena hereafter to be described.

841. *Prop.* 3. If a ray be completely polarized by reflexion at the surface of one medium, and the reflected ray completely transmitted or absorbed at that of a second, Required the inclination of the two surfaces to each other?

Let a and a' be the polarizing angles of the respective media; then, since the planes of reflexion are at right angles to each other, and a, a' are the angles of incidence, if we call I the inclination required, we shall have by Art. 104, $\cos I = \cos a \,.\, \cos a'$. Now, if μ, μ' be the refractive indices of the media, we have $\tan a = \mu$, $\tan a' = \mu'$, and therefore

$$\tan I = \sqrt{\mu^2 + \mu'^2 + \mu^2 \mu'^2}.$$

842 *Corol.* 1. If the media be both alike,

$$\tan I = \mu \,.\, \sqrt{2 + \mu^2}; \text{ or } \cos I = \frac{1}{1 + \mu^2}.$$

Thus, in the case of crown-glass, $\mu = 1.535$ and $I = 72^\circ\, 40'$, as in Art. 825.

843. Method of determining refractive indices by polarization.

By the help of this law, connecting the angle of polarization with the refractive index, we may easily deduce the one from the other. This affords a valuable and ready resource in cases to which other methods can hardly be applied, for ascertaining the refractive powers of media, which are either opake, or in such small or irregularly shaped masses, that they cannot be used as prisms. For ascertaining the angle of polarization, only one polished surface, however small, is necessary, and we have only to receive a ray reflected from it on a blackened glass, or other similar medium of known refractive index, *at the polarizing angle*, and in a plane perpendicular to that at which it is reflected by the surface under examination. For this purpose it is convenient to have the glass plate (or, which is better, a polished plate of obsidian or dark coloured quartz) set in a tube diagonally, so as to reflect laterally the ray which traverses the axis of the tube. At the other end, the substance to be examined must be fixed on a revolving axis perpendicular to the axis of the tube, and having its plane adjusted so as to be parallel to the former, which must then be turned round till the dispersed light of the clouds, reflected by it, is entirely extinguished by the obsidian plate, and the inclination of the reflecting surface to the axis of the tube in this situation may be measured by a divided circle, connecting with the axis of rotation. By this means we may ascertain the polarizing angles, and therefore the refractive indices of the smallest crystals, or of polished stones, gems, &c., set in such a manner as not to admit of other modes of examination. To insure a fixed zero point on the graduated circle, the following mode (among many others) may be resorted to. Let a polished metallic reflector or small piece of looking-glass be permanently attached to the revolving axis, so that its plane shall be perpendicular to the axis of the tube, when the index of the divided circle marks 0° 0′. This adjustment being made once for all, let the surface to be examined be attached by wax or otherwise, not to the axis itself, but to a ring turning stiffly on it. Then, bringing the image of the sun, or any very distant object, sufficiently bright or well defined, seen in the reflector, to coincide with any other equally well defined, and also at a great distance, alter the attachment of the substance by pressure on the wax, and by turning round the ring, till a similar coincidence is obtained when the eye is transferred to *it*. Then we are assured that the two surfaces are parallel, and that therefore the reading off on the circle measures the true angle between the axis of the tube and the perpendicular, or the angle of reflexion, or at least differs from it only by a constant quantity, which may be ascertained at leisure, and applied as index error. (This mode of bringing a movable surface to a fixed position with respect to the divisions of an instrument, is applicable to a great variety of cases, and is at once convenient and delicate.)

844. Irregular polarization by glass surfaces.

Dr. Brewster has remarked, that glass surfaces frequently exhibit remarkable, and apparently unaccountable, deviations from the general law; but on minute examination he found that this substance is liable to a superficial tarnish, or formation of infinitely thin films of a different refractive power from the mass of glass beneath. As the polarized ray never penetrates the surface, its angle of polarization is determined solely by this film, which is too thin to admit of any direct measure of its refractive index. When this tarnish has gone to a great extent, scales of glass detach themselves, as is seen in very old windows, (especially those of stables,) and even in green glass bottles which have long lain in damp situations, and which acquire a coat actually capable of being mistaken for gilding.

845. Action of metallic surfaces.

In metallic or adamantine bodies, which polarize light but imperfectly, that angle at which the reflected beam approaches nearer in its character to those described as of polarized light, is to be taken for the angle of polarization, and from it the refractive power may still be found. The results deduced by this means for metallic bodies, agree with those obtained from the quantity of light reflected, in assigning very high refractive powers to them. Thus, for steel the polarizing angle is found to be above 71°, and for mercury $76\frac{1}{2}^\circ$, and their indices of refraction are, therefore, respectively 2.85 and 4.16. This latter result, indeed, differs greatly from that of Art. 594, but the observations are so uncertain, and the angle of greatest polarization so indefinitely marked, (not to mention the errors to which a determination of the reflective power itself is liable to,) that we cannot expect coincidence in such determinations. Perhaps 5.0 may be taken as a probable index.

846. The law of polarization announced by Dr. Brewster is general, and applies as well to the polarization of light at the separating surfaces of two media in contact, as at the external or internal surface of one and the same medium. He has attempted to deduce from it several theoretical conclusions, as to the extent and mode of action of the reflecting and refracting forces, for which we must refer the reader to his Paper on the subject *Philosophical Transactions*, 1816

847. Partial polarization.

If a ray be reflected at an angle greater or less than the polarizing angle, it is *partially polarized*, that is to say, when received at the polarizing angle on another reflecting surface, which is made to revolve round the reflected ray without altering its inclination to it, the twice reflected ray never vanishes entirely, but undergoes alternations of brightness, and passes through states of maxima and minima which are more distinctly marked according as the angle of the first reflexion approaches more nearly to that of complete polarization. The same is observed when a ray so *partially* polarized is received on a tourmaline plate, revolving (as above described) in its own plane. It never undergoes complete extinction, but the transmitted portion passes through alternate maxima and minima of intensity, and the approach to complete extinction is the nearer the nearer the angle of reflexion has been to the polarizing angle. We may conceive a partially polarized ray to consist of two unequally intense portions; one completely polarized, the other not at all. It is evident that the former, periodically passing from evanescence to its total brightness, during the rotation of the tourmaline or reflector, while the latter remains constant in all positions, will give rise to the phenomenon in question. And all the other characters of *a partially polarized ray* agreeing with this explanation, we may receive it as a principle, that when a surface does not completely polarize a ray, its action is such as to leave a certain portion completely unchanged, and to impress on the remaining portion the character of complete polarization. Thus we must conceive polarization as a property or character not susceptible of *degree*, not capable of existing sometimes in a more, sometimes in a less, intense state. A single elementary ray is either wholly polarized or not at all. A *beam* composed of many *coincident rays* may be partially polarized, inasmuch as some of its component rays only may be polarized, and the rest not so. This distinction once understood, however, we shall continue to speak of a ray as wholly or partially polarized, in conformity with common language. We shall presently, however, obtain clearer notions on the subject of *unpolarized* light, and see reason for discarding the term altogether.

How conceived.

848. Polarization by several reflexions in one plane.

If a ray be partially polarized by reflexion, Dr. Brewster has stated that a second reflexion *in the same plane* renders this polarization more complete, or diminishes the ratio of the unpolarized to the polarized light in the reflected beam; and that by repeating the reflexion, the ray may be completely polarized, although none of the angles of reflexion be the polarizing angle. Thus he found, that one reflexion from glass at 56° 45′ of incidence, two at incidences of 62° 30′ or at 50° 20′, three at 65° 33′ or at 46° 30′, four at 67° 33′ or 43° 51′, and so on, alike sufficed to operate the complete polarization of the ray finally reflected, provided all the reflexions were made in one plane. At angles above 82°, or below 18°, more than 100 reflexions were required to produce complete polarization.

§ IV. *Of the Laws of Reflexion of Polarized Light.*

849. When polarized light is reflected at any surface, transparent or otherwise, the *direction* of the reflected portion is precisely the same as in the case of natural light, the angle of reflexion being equal to that of incidence; the laws we are now to consider are those of the intensity of the reflected light, and of the nature of its polarization after reflexion.

850. Intensity of reflection of a polarized ray incident at the polarizing angle in any plane.

One essential character of a polarized ray is, its insusceptibility of reflexion in a plane at right angles to that of its polarization when incident at a particular angle, *viz.* the polarizing angle of the reflecting surface. In this case, the intensity I of the reflected ray is 0. In all other cases it has a certain value, which we are now to inquire. Let us suppose, then, to begin with the simplest case, that the polarized ray fails on the reflecting surface at a constant angle of incidence, equal to its polarizing angle, and that the reflecting surface is turned round the incident ray as an axis, so that the plane of incidence shall make an angle ($= a$) of any variable magnitude with the plane of polarization. It is then observed, as we have seen, that when $a = 90°$ or $270°$, we have $I = 0$, and when $a = 0°$, or $180°$, I is a maximum. Hence, it is clear that I is a periodic function of a, and the simplest form which can be assigned to it (since negative values are inadmissible) is $I = A \,.\, (\cos a)^2$. This value, which was adopted by Malus on no other grounds than those we have stated, is however found to represent the variation of intensity throughout the quadrant, with as much precision as the nature of photometrical experiments admits, and we must therefore receive it as an empirical law at present, for which any good theory of polarization ought to be capable of assigning a reason *a priori*.

851. An unpolarized ray equivalent to two polarized ones.

A remarkable consequence follows from this law. It is that, so far as the intensity of the reflected ray is concerned, an ordinary or unpolarized ray may be regarded as composed of two polarized rays, of equal intensity, having their planes of polarization at right angles to each other. For such a compound ray being incident on a reflecting surface, as above supposed, if a be the inclination of the plane of polarization of one portion to that of incidence, $90 - a$ will be that of the other, and, therefore, since

$$A \,.\, (\cos a)^2 + A \,.\, (\cos \,.\, 90 - a)^2 = A, \qquad (a)$$

the reflected ray will be independent of a, and therefore no variation of intensity will be perceived on turning the reflecting surface round the incident ray as an axis, which is the distinguishing character of unpolarized light. *Any such pair of rays as here described are said to be oppositely polarized.*

852. Fresnel's general law for the intensity of a reflected ray

When the polarized ray is not incident at the polarizing angle, but at any angle of incidence, the law of intensity of the reflected ray is more complicated. M. Fresnel has stated the following as the general expression for it. Let the intensity of the incident ray be represented by unity, and calling, as before, a the inclination of the plane of incidence to that of primitive polarization, and i the angle of incidence, i' the corresponding angle of refraction. Then will the intensity of the reflected ray be represented by

$$I = \frac{\sin^2(i - i')}{\sin^2(i + i')} \cdot \cos^2 \alpha + \frac{\tan^2(i - i')}{\tan^2(i + i')} \cdot \sin^2 \alpha. \qquad (b)$$

This formula is in some degree empirical, resulting partly from theoretical views, of which more hereafter, and being not yet verified, or indeed compared with experiment, except in particular cases, by M. Arago, whose results, so far as they go, are consonant with it.

853. Particular cases examined. It will be well to examine some of these. And first, then, when $\alpha = 90°$, and $i =$ the polarizing angle of the reflecting surface, we have by (835 and 836) $i + i' = 90°$, and therefore $\tan(i + i') = \infty$, so that $I = 0$. In these circumstances, then, the reflected ray is completely extinguished, which agrees with fact.

854. Perpendicular incidence. 2dly. When the incidence is perpendicular, we have, in this case, both i and i' vanishing, and each term of I takes the form $\frac{0}{0}$. Now at the limit we have (μ being the refractive index) $i = \mu \, . \, i'$, and very small arcs being equal to their sines or tangents, we have $\sin(i - i') = i'(\mu - 1)$; $\sin(i + i') = i'(\mu + 1)$, and so for the tangents. Consequently,

$$I = \left(\frac{\mu - 1}{\mu + 1}\right)^2 . (\cos^2 \alpha + \sin^2 \alpha) = \left(\frac{\mu - 1}{\mu + 1}\right)^2,$$

which agrees with the expression deduced by Dr. Young and M. Poisson, (Art. 592,) for the intensity of the reflected ray in the case of unpolarized light. And if we regard the unpolarized ray as composed of two rays, each of the same intensity, ($= \frac{1}{2}$) polarized in opposite planes, the reason of the coincidence will be evident.

855. 3d. When $\alpha = 0$, or the plane of polarization coincides with the plane of incidence, we have, in general,

$$I = \frac{\sin^2(i - i')}{\sin^2(i + i')}. \qquad (c)$$

856. 4th. When $\alpha = 90°$, or when the plane of polarization is at right angles to the plane of incidence,

$$I = \frac{\tan^2(i - i')}{\tan^2(i + i')}. \qquad (d)$$

857. Intensity of reflexion of natural light. 5th. When $\alpha = 45$,

$$I = \tfrac{1}{2}\left\{\frac{\sin^2(i - i')}{\sin^2(i + i')} + \frac{\tan^2(i - i')}{\tan^2(i + i')}\right\}. \qquad (e)$$

This last is the same result with that which would result from the supposition of two equal rays polarized, the one *in*, the other *perpendicularly to*, the plane of incidence, and each of half the intensity with the incident beam. It is therefore the general expression for the intensity of a ray of natural or unpolarized light reflected at an incidence $= i$ from the surface. The expressions in Art. 592 apply only to perpendicular incidences. We are thus furnished very unexpectedly with a solution of one of the most difficult and delicate problems of experimental Optics. Bouguer is the only one who has made any extensive series of photometrical experiments on the intensity of light reflected from polished surfaces at various angles, but his results are declared by M. Arago to be very erroneous, which is not surprising, as the polarization of light was unknown to him, and its laws might affect the circumstances of his experiments in a variety of ways.

858. Polarization of the light of the sky. One only need be mentioned, as every optical experimentalist ought to be aware of, and on his guard against it, it is that the light of clear, blue sky, is always partially polarized in a plane passing through the sun, and the part from which the light is received. The polarization is most complete in a small circle, having the sun for its pole, and its radius about 78°, (according to an experiment not very carefully made.) Now the semi-supplement of this (which is the polarizing angle) is 51°, which coincides nearly with the polarizing angle of water, (52° 45′.) Thus strongly corroborating Newton's theory of the blue colour of the sky, which he conceives to be the blue of the first order, reflected from particles of water suspended in the air. Dr. Brewster is the first, we believe, who noticed this curious fact. But to return to our subject.

859. Case of a ray partially polarized. When the incident ray is only partially polarized, we may regard it as consisting of two portions: the one, which we shall represent by a, completely polarized in a plane, making the angle α with that of incidence; the other $= 1 - a$ in its natural state, or, if we please, composed of two portions $\left(\frac{1 - a}{2}\right)$, one polarized in the plane of incidence, and one at right angles to it. The intensity of the reflected portion of the former is equal to

$$a \, . \, \frac{\sin^2(i - i')}{\sin^2(i + i')} \cos^2 \alpha + a \, . \, \frac{\tan^2(i - i')}{\tan^2(i + i')} \, . \, \sin^2 \alpha,$$

and that of the latter will be represented by

$$\frac{1 - a}{2}\left\{\frac{\sin^2(i - i')}{\sin^2(i + i')} + \frac{\tan^2(i - i')}{\tan^2(i + i')}\right\}$$

therefore, their sum, or the total reflected light, will be

$$\frac{\sin^2(i - i')}{\sin^2(i + i')} \cdot \frac{1 + a \, . \cos 2\alpha}{2} + \frac{\tan^2(i - i')}{\tan^2(i + i')} \cdot \frac{1 - a \, . \cos 2\alpha}{2}.$$

The above formulæ, it must be observed, apply only to the case of reflexion from the surfaces of uncrystallized media. The consideration of those where crystallized surfaces are concerned, cannot be introduced in this part of the subject.

$= a + b\,a + b^2\,a + \ldots\ b^{n-1}\,a = a\,.\,\frac{1 - b^n}{1 - b}$, and an unpolarized portion $= b^n$, so that no finite number of plates could ever *completely* polarize the whole transmitted beam.

867. Dr. Brewster's theory of imperfect polarization. Brewster's general law.

On the other hand, if the unpolarized portion b of the transmitted beam $a + b$ be more disposed than before, as Dr. Brewster conceives, to subsequent polarization, the progression above stated, instead of converging according to the law of a geometric progression, will converge more rapidly, or may even suddenly terminate under certain physical conditions. Now, Dr. Brewster states it as a general law, deduced from his own experiments, that *If a pencil of light be incident on a number of uncrystallized plates, inclined at the same or different angles, but all their surfaces being perpendicular to the plane of the first incidence, the total polarization of the transmitted pencil will commence when the sum of the tangents of the angles of incidence on each plate is equal to a certain " constant quantity due to the refractive power of the plates, and the intensity of the incident pencil."* This last phrase, which makes the number and position of the plates necessary to operate total polarization, depend on the intensity of the incident light, shows evidently that the *total polarization* here understood, is not mathematically, but only approximatively total. In fact, he states, this constant quantity for crown glass plates, and *for the flame of a wax candle at* 10 *feet distance*, to be equal to the number 41.84. In other words, the remainder of unpolarized light for this intensity of illumination, becomes insensible. Considered in this light, we regard Dr. Brewster's experiments as by no means incompatible with the law of decrease indicated by the geometric progression above-mentioned, and the contrary sense which has been put upon this expression by M. Arago, or his commentator, (*Encyclop. Brit. Supp.*, vol. vi. part 2, *Polarization of Light*,) appears to us strained beyond what strict criticism authorizes.

Conceiving, then, as we do, that no decided incompatibility in matter of fact exists between the statements of these distinguished philosophers, we cannot but regard as most simple, that doctrine which recognises no change of physical character in the unpolarized portion of either the transmitted or reflected beam. (See Art. 848.)

868. Internal reflexions between the plates.

In what has been above said of the polarization of the transmitted ray, we have not taken into consideration that part of the light reflected at each surface which is reflected back again, and traversing (partially at least) all the plates, mixes with the transmitted beam, and, being in an opposite plane, destroys a part of its polarization.

869. Phenomena of piles of plates exposed to polarized light.

If a pile of parallel glass plates be exposed to a polarized ray, so that the angle of incidence be equal to the polarizing angle, and then turned round the ray as an axis preserving the same inclination, the following phenomena take place:

1. When the plane of incidence is at right angles to that of the ray's polarization, *the whole of the incident light is transmitted*, (except what is destroyed by absorption within the substance of the glass, or lost by irregular reflexion from the inequalities in the surface arising from defective polish,) and this holds good whatever be the number of the plates. The polarization of the transmitted ray is unaltered.

2. As the pile revolves round the incident ray as an axis, a portion of the light is reflected, and this increases till the plane of incidence is coincident with the plane of primitive polarization, when the reflected light is a maximum. Now, M. Arago assures us, that the quantity of *polarized* light reflected from each plate is greater in proportion to the intensity of the incident beam than if natural light had been employed; and the same proportion holding good at each plate, the transmitted ray, however intense it may have been at first, will be weakened in geometrical progression with the number of plates, and at length will become insensible; so that in this situation the pile will present the phenomenon of an opaque body. In this reasoning, the light reflected backwards and forwards between the plates is neglected; but as it is all polarized in the same plane, and as in this situation the reflexions, however frequent, produce no change in its plane of polarization, all the reflected rays are in the same predicament; and, supposing the number of plates very great, the total extinction of the transmitted light will ultimately (though less rapidly) take place.

870. Phenomena of piles of plates, and of tourmaline plates compared.

Hence, a pile of a great number of glass plates inclined at an angle equal to the complement of the polarizing angle (35° ±) to a polarized ray ought to present the same phenomenon with a plate of tourmaline cut parallel to the axis of its primitive rhomboid, alternately transmitting and extinguishing the whole of the light in the successive quadrants of its rotation, and being thus either opaque or transparent, according to its position. The analogy, however, cannot fairly be pushed farther, so as to deduce from this principle an explanation of the phenomena of the tourmaline; for, although it be true that a plate of tourmaline so cut, *is* composed of laminæ inclined to its surface, these laminæ are in optical contact; and, moreover, their position with respect to the surface is not the same in plates cut in all directions around the axis, because although an infinite number of plates may be cut containing *the axis* of a rhomboid in their planes, only three can have the same relation to its several *faces*, parallel to which the component laminæ must be supposed to lie. Moreover, the phenomena are not produced, unless the tourmaline be coloured. The analogy between piles of glass plates and laminæ of agate (of which more presently) is also, we are inclined to think, more apparent than real.

871. Further analogy.

A pile of plates such as described above presents, moreover, the same difference of phenomena when exposed to polarized and unpolarized light, that a plate of tourmaline does; since in the latter case, supposing the pile sufficiently numerous, one half the incident light is transmitted, completely polarized in a plane perpendicular to that of incidence.

872. The laws which regulate the polarization of a pencil transmitted by a transparent surface, inclined at any proposed angle to the incident ray, and in any plane to that of its primitive polarization (supposing it polarized) remain open to experimental investigation.

§ VI. *Of the Polarization of Light by Double Refraction.*

Light polarized by double refraction oppositely in the two pencils. Experiments in proof thereof.

873. When a ray of natural light is divided into two by double refraction, in such a manner that the two pencils at their final emergence remain distinct and susceptible of separate examination, they *are both found completely polarized, in different planes*, exactly, or nearly, at right angles to each other. To show this, take a pretty thick rhomboid of Iceland spar, and, covering one side of it with a blackened card, or other opaque thin substance, having a small pinhole through it, hold it against the direct light of a window or a candle, with the covered surface from the eye. Two images of the pinhole will then be seen: one, undeviated from the line joining the eye and the real hole, by the ordinarily refracted rays; and the other, deviating from that line, in a plane parallel to the principal section of the surface of incidence, by the extraordinary. These images will appear, to the naked eye, of equal brightness; but, if we interpose a plate of tourmaline, (as already described,) and turn the latter about in its own plane, they will be rendered unequal, and will appear and vanish alternately at every quarter revolution of the tourmaline; the *ordinary* image being always at its maximum of brightness, and the *extraordinary* one extinct, when the axis of the tourmaline plate is perpendicular to the principal section of the surface of incidence, and *vice versâ* when parallel to it.

Experiment varied.

874. The same thing happens, when, instead of examining the two images through a tourmaline plate, we receive their light on a glass plate inclined at the polarizing angle to it, and turn this plate round the ordinary ray as an axis. The images will appear and disappear alternately, as the reflector performs successive quadrants of its revolution.

875. Hence, we see that the two pencils are *completely* and oppositely polarized; the ordinary pencil in a plane passing through the axis of the rhomboid; the extraordinary one in a plane at right angles to it.

Another form of the experiment.

876. The same phenomenon is much better seen by using a *prism* of any double refracting crystal, having such a refracting angle as to give two distinctly separated images of a distant object, (as a candle.) These appear and disappear alternately at quarter revolutions of a tourmaline plate or glass reflector, and are of equal brightness at the intermediate half-quarters.

Transmission of polarized light through doubly refracting media.

877. Double refraction, then, polarizes the two refracted pencils oppositely, into which an unpolarized incident ray is separated. Let us now see what happens to a *polarized ray*. For this purpose let a plate of glass be laid down before an open window, so as to polarize the reflected light, and hold the rhomboid of Iceland spar (covered as before) with the covered side from the eye, not (as in the former experiment) against the direct light, but inclined downwards, against the reflected light from the glass. Then, generally speaking, two images of the pinhole will be seen, but of *unequal* intensities; and, *if we turn round the rhomboid, in the plane of the covered side, these images will be seen to vary perpetually in their relative brightness, the one increasing to a maximum, while the other vanishes entirely, and so on reciprocally.* When the principal section of the rhomboid is in the plane of reflexion (*i. e.* of polarization) of the incident ray, the ordinary image is a maximum; the extraordinary is extinct, and *vice versâ* when these two planes make a right angle. The experiment may be advantageously varied by using a doubly refracting prism; and, while looking through it at the polarized image of a candle, turning it round slowly in the plane bisecting its refracting angle.

Unequal division of the light between the two refracted pencils.

878. This experiment leads us to the following remarkable law, *viz.* that if a ray, at its incidence on a doubly refracting surface, be polarized in the plane parallel to the principal section, it will not suffer bifurcation, but will pass wholly into the ordinary image; if, on the other hand, its plane of primitive polarization be perpendicular to the principal section, it will pass entirely into the extraordinary image. In intermediate positions of the plane of primitive polarization, bifurcation takes place, and the ray is *unequally* divided between the two refracted pencils, in every case except when the plane of primitive polarization makes an angle of 45° with the principal section. In general, if a be the angle last mentioned, and A the incident light, (supposing none lost by reflexion,) $A \cdot \cos^2 a$ will be the intensity of the ordinary, and $A \cdot \sin^2 a$ of the extraordinary pencil, their sum being A.

Huygens's experiment

879. All these changes and combinations are exhibited in the following remarkable experiment of Huygens, which, reasoned on by himself and Newton, first gave rise to the conception of a polarity, or distinction of *sides*, in the rays of light when modified by certain processes. Take two pretty thick rhomboids of Iceland spar, (which should be very transparent, as they are easily procured,) and lay them down one upon the other, so as to have their homologous sides parallel, or so that the molecules of each shall have the same relations of situation as if the two rhomboids were contiguous parts of one larger crystal. They should be laid on a sheet of white paper having a small, very distinct, and well-defined black spot on it. This spot then will be seen double through the combined crystals, as if they were one, (*a*, fig. 173,) and the line joining the images will be parallel to the principal section of either. Now, let the upper crystal be turned slowly round in a horizontal plane on the lower, and two new images will make their appearance between the two first seen, which, at first, are very faint, as at *b*, fig. 173, and form a very elongated rhombus with the two former. They increase, however, in intensity, while the other pair diminishes, till the angle of rotation of the upper crystal is 45°, where the appearance of the images is as at *c*. Continuing the rotation, the rhomb approaches to a square, as at *d*, and the two original images have become extremely faint; and when the rotation is just 90°, they will have disappeared altogether, leaving the others diagonally placed, as at *e*. As the rotation still proceeds, they reappear and increase in brightness, till the angle of revolution $= 90° + 45° = 135°$, when the images are all equal, as at *f*; after which the original images still increasing, and the others diminishing, the appearance *g* is produced, which, on the completion of a precise half revolution, passes into *h* by the union of both the original images into one, and the total evanes- Fig. 137.

cence of the other pair. In this case only single refraction (apparently) happens; or, rather, the double refractions of the two rhomboids taking place in opposite directions, and being equal in amount, compensate each other. Unless, however, the rhomboids be of exactly equal thickness, this precise compensation will not take place, and the images will remain distinct, though at a minimum of distance. We may express the four images thus:

O *o*, the image ordinarily refracted by both rhomboids.
O *e*, the image refracted ordinarily by the first, and extraordinarily by the second.
E *o*, the image refracted extraordinarily by the first, and ordinarily by the second.
E *e*, the image refracted extraordinarily by both.

Then, if A be the intensity of the incident light, supposing none lost by reflexion or absorption,

$$\mathrm{O}\,o = \tfrac{1}{2}\,\mathrm{A}\,.\,\cos^2 a = \mathrm{E}\,e; \quad \mathrm{O}\,e = \tfrac{1}{2}\,\mathrm{A}\,.\,\sin^2 a = \mathrm{E}\,o,$$

and the sum of all the four images = A.

880. The same phenomena (with some unimportant variations) take place when we apply two doubly refracting prisms one behind the other close to the eye, and view a distant object through them, turning one round on the other. The rationale of these phenomena follows so evidently from the laws stated in Art. 875 and 878, that it will not be necessary to enlarge on it.

881. Use of an achromatic double refracting prism.

The property of a double refraction, in virtue of which a polarized ray is unequally divided between the two images, furnishes us with a most convenient and useful instrument for the detection of polarization in a beam of light, and for a variety of optical experiments. It is nothing more than a prism of a doubly refracting medium rendered achromatic by one of glass, or still better, by another prism of the same medium properly disposed, so as to increase the separation of the two pencils. The former method is simple; and, when large refracting angles are not wanted, the uncorrected colour in one of the images is so small as not to be troublesome. It is most convenient to make the refracting angle such as to produce an angular separation of about 2° between the images. Thus, in fig. 174, let A B C G F be a prism of Iceland spar, cut in such a manner (we will at present suppose) that the refracting edge C G shall contain the axis of the crystal; and let it be achromatized as much as possible by a prism of glass C D E F G. Then, if Q be a small, colourless, luminous circle of about a degree or two in apparent diameter, as seen by an eye at O, the interposition of the combined prisms will divide it into two, Q and *q*. Now, if the light of Q be completely unpolarized, these two will remain exactly of equal intensity while the prism A B C G is turned round in a plane at right angles to the line of vision. But if any polarity exist in the original light, the two images Q, *q* will, in turning round the prism, appear alternately more and less bright one than the other; and being always seen immediately side by side, the least inequality, and consequently the least admixture of polarized light in the incident beam, will be detected.

Fig. 174. First achromatized by glass.

882. Dr. Wollaston's mode of doubling the separation of images. Fig. 175.

Iceland spar, from its very great double refraction, is commonly used for these prisms; but it is so soft, and its structure so lamellar, as to be difficult to polish, and still more so to preserve polished. We have found quartz and limpid topaz to answer extremely well. The following ingenious mode of rendering available the low double refraction of the former, due to Dr. Wollaston, is here eminently useful. Let A B C D *a b c d* and E F G H *e f g h* (fig. 175) be two halves of a hexagonal prism of quartz (the form it affects) produced by a section parallel to two of the sides. In the vertical face A D *d a* draw any line L K parallel to the sides, and therefore to the axis of the prism, (which is also that of double refraction,) and join C L, *c k*. Then a plane C L *k c* will cut off a prism C L K *d c* D, having L *k*, D *d*, or C *c*, for its refracting edges, either of which is parallel to the axis. Again, in the other half of the prism join E *f* and H *g*, and cut the prism by a plane passing through these lines; then, regarding either portion as a double refracting prism, having for refracting edges the lines E H, *f g*, *these* will have the axis of double refraction perpendicular to their refracting edges; and, in particular, the axis will lie *in* the faces H E *e h*, or F G *g f* at right angles to H E or *f g*. If, then, we take care to make the refracting angle C L D of the prism C L K *d* c D equal to that of the edge H E of the prism H E *e f g h*; and if we make these two prisms act in opposition to each other, placing the edge H E opposite to D *d*, and the edge *h e* opposite to K L; and having thus brought the two surfaces D L *k d* and H E *e h* in contact, cement them together with mastic, or Canada balsam, it is evident, that their principal sections will be at right angles to each other; and therefore only two images will be formed, the whole of the extraordinary ray of the one prism passing into the ordinary image of the other, and *vice versâ*. Now, to see how this acts to double the separation of the images, let us conceive *m n* to be a luminous line viewed through one of the prisms with its edge downwards and horizontal. It will be separated into two images, *e* and *o*, the one more raised than the other. Suppose the ordinary image to be most refracted. Then, if we interpose the other prism with its edge upwards, both these images will be refracted downwards; but the ordinary image *o*, which was before *most* raised, now undergoing extraordinary refraction, is *least depressed*, and comes into the position *o e*, while the extraordinary one *e*, which was before *least raised* is now *most depressed*, and comes into the situation *e o*; and it is evident that (the refracting angles being equal, and the double refraction of the two prisms the same) the line *o e* will fall as far short of the original line *m n*, as *e o* surpasses it, *viz.* by a quantity equal to the distance between the two first images *o* and *e*; so that the distance between the twice refracted images is double that of those which have undergone only one refraction. We have found this combination extremely advantageous, as quartz takes a very perfect polish, and from its hardness is not liable to injury from scratches.

883. Action of crystals possessing no double refraction.

Crystals which have no double refraction may be regarded as limits of those which have, or as crystals in which the two rays are propagated with equal velocity, and therefore undergo no bifurcation; or, in other words, in which the images formed coincide. In this case we should expect to find no polarization of the emergent light, because the two pencils, being polarized at right angles to each other, form together a single ray having the characters of unpolarized light. This is verified by experiment. The light transmitted by fluor spar, for instance, exhibits no signs of polarization, unless so far as the ordinary action of the surface goes. We are aware of no experiments indicating how far the action of the *surfaces* of feebly double refracting crystals may modify their polarizing forces, or rather their effects on a ray which has penetrated below the surface; or, in other words, how far piles of crystallized laminæ may have an analogous or different action from those of uncrystallized. Dr. Brewster, indeed, found piles of mica films to polarize light by transmission, like glass piles, but the subject is open to further inquiry.

§ VII. *Of the Colours exhibited by Crystallized Plates when exposed to Polarized Light, and of the Polarized Rings which surround their Optic Axes.*

884. This splendid department of Optics is entirely of modern and, indeed, of recent origin. The first account of the colours of crystallized plates was communicated by M. Arago to the French Institute in 1811, since which period, by the researches of himself, Dr. Brewster, M. Biot, M. Fresnel, and, latterly, also of M. Mitscherlich, and others, it has acquired a developement placing it among the most important as well as the most complete and systematic branches of optical knowledge. As might be expected, under such circumstances, as well as from the state of political relations, and the consequent limited intercourse between Britain and the Continent at the period mentioned, an immense variety of results could not but be obtained independently, and simultaneously, or nearly simultaneously, on both sides of the channel. To the lover of knowledge, for its own sake,—the *philosopher*, in the strict original sense of the word,—this ought to be matter of pure congratulation; but to such as are fond of discussing rival claims, and settling points of scientific precedence, such a rapid succession of interesting discoveries must, of course, afford a welcome and ample supply of critical points, the seeds of an abundant harvest of dispute and recrimination. Regarding, as we do, all such discussions, when carried on in a spirit of rivalry or nationality, as utterly derogatory to the interests and dignity of science, and as little short, indeed, of sacrilegious profanation of regions which we have always been accustomed to regard only as a delightful and honourable refuge from the miserable turmoils and contentions of interested life, we shall avoid taking any part in them; and, taking up the subject (to the best of our abilities and knowledge) as it is, and avoiding, as far as possible, all reference to misconceived facts and over-hasty generalizations, which in this as in all other departments of science, have not failed (like mists at daybreak) to spread a temporary obscurity over a subject imperfectly understood, shall make it our aim to state, in as condensed a form as is consistent with distinctness, such general facts and laws as seem well enough established to run no hazard of being overset by further inquiry, however they may merge hereafter in others yet more general;—a consummation devoutly to be wished.

885. First method of exhibiting the colours of crystallized plates. Instanced in mica.

The general phenomenon of the coloured appearances to which this section is devoted, may be most readily and familiarly shown as follows. Place a polished surface of considerable extent (such as a smooth mahogany table, or, what is much better, a pile of ten or a dozen large panes of glass laid horizontally) close to a large open window, from which a full and uninterrupted view of the sky is obtained; and having procured a plate of mica, of moderate thickness, (about a thirtieth of an inch, such as may easily be obtained, being sold in considerable quantity for the manufacture of lanterns,) hold it between the eye and the table, or pile, so as to receive and transmit the light reflected from the latter as nearly as may be judged at the polarizing angle. In this situation of things, nothing remarkable will be perceived, however the plate of mica be inclined; but if instead of the naked eye we look through a tourmaline plate, having its axis vertical, the case will be very different. When the mica plate is away, the tourmaline will destroy the reflected beam, and the surface of the table, or pile, will appear dark and non-reflective; at least in one point, on which we will suppose the eye to be kept steadfastly fixed. No sooner is the mica interposed, however, than the reflective power of the surface appears to be suddenly restored; and on inclining the mica at various angles, and turning it about in its own plane, positions will readily be found in which it becomes illuminated with the most vivid and magnificent colours, which shift their tints at the least change of position of the mica, passing rapidly from the most gorgeous reds to the richest greens, blues, and purples. If the mica plate be held perpendicular to the reflected beam, and turned about in its own plane, two positions will be found in which all colour and light disappears; and the reflected ray is extinguished, as if no mica was interposed. Now, if we draw on the plate with a steel point two lines corresponding to the intersection of the mica with a vertical plane passing through the eye in either of these two positions, we shall find that they make an exact right angle. For the moment, let us call these lines A and B; and let a plane drawn through the *line* A, perpendicular to the plate, be called *the section* A; and one similarly drawn through the line B, *the section* B. Then we shall observe further, that when we turn the plate from either of these positions, 45° round, in its own plane, so that the sections A and B shall make angles of 45° with the plane of reflexion, (*i. e.* of polarization of the incident ray,) the transmitted light will be a maximum.

Two remarkable sections of the crystallized plate.

886. Law of the tints exhibited at a perpendicular incidence.

If the thickness of the mica do not exceed $\frac{1}{30}$th of an inch, it will be coloured in this position; if materially greater, colourless; and if less, more and more vividly coloured, and with tints following closely the succession of the reflected series of the colours of thin plates, and, like them, rising in the scale, or approaching the central tint (black) as the thickness is less. The analogy in this respect, in short, is complete, with the exception of the enormous difference of thickness between the mica plate producing the tints in question, and those required to produce the Newtonian rings. It appears by measures made in the manner hereafter to be described, that the tint exhibited by a plate of mica exposed perpendicularly to the reflected ray, as above described, is the same with that reflected by a plate of air of $\frac{1}{400}$th part of the thickness of the mica employed.

887. Tints exhibited in the two sections above mentioned.

If the mica (still exposed perpendicularly to the ray) be turned round in its own plane, the tint does not change, but only diminishes in intensity as its section A or B approaches the plane of polarization of the incident light. When, however, the plate is not exposed perpendicularly, this invariability no longer obtains; and the changes of tint appear in the last degree capricious and irreducible to regular laws. In two situations, however, the phenomena admit a simple view. These are when the sections A and B are both 45° from the plane of polarization, and the mica plate is inclined backwards and forwards *in the plane* of one or the other of these sections. This condition is easily attained by first holding the plate perpendicularly to the reflected ray; then turning it in its own plane till the lines A, B are each 45° inclined to the vertical plane, then finally causing it to revolve about either of these lines as an axis. It will then be seen that when made to revolve *round* one of them (as A) or *in the plane* of the section B, the tint, if white, will continue white at all angles of inclination; but if coloured, will *descend* in the scale of the coloured rings, growing continually less highly coloured, till it passes, after more or fewer alternations, into white; after which, further inclination of the plate will produce no change. On the other hand, if made to revolve *round* B, or *in the plane of* A, the tints will *rise* in the scale of the rings; and when the mica plate is inclined either way, so as to make the angle of incidence about 35° 3′, will have attained its maximum, corresponding to the black spot in the centre of Newton's rings. In this position of the plate, the reflected beam is totally extinguished by the tourmaline, as if the sections A or B had been vertical. But if the angle of incidence be still further increased the colours reappear, and *descend* again in the scale of the rings, passing through their whole series to final whiteness. We take no notice here of a slight deviation from the strict succession of the Newtonian colours, which is observed in the higher orders of the tints, as we shall have more to say respecting it hereafter.

888. Characters of the two most remarkable sections.

We see, then, that the sections A and B, though agreeing in their characters in the case of a perpendicular exposure of the mica, yet differ entirely in the phenomena they exhibit at oblique incidences. If the incidence take place in the plane of the section B, the tint descends, on both sides of the perpendicular, *ad infinitum.* While, if the incidence be in the section A, it rises to the central black, which it attains at equal incidences on either side of the perpendicular (35° 3′), and then descends again *ad infinitum*, or to the composite white at the other extreme of the scale.

889. The principal section defined. Contains the two optic axes. Characters of these axes.

The section A, then, (which, for this reason, we will call the *principal section* of the mica plate,) is characterised by containing two remarkable lines inclined at equal angles to the surface of the plate, along either of which, if a polarized ray be incident, its polarization will not be disturbed by the action of the plate. To satisfy ourselves of this, we have only to fix the mica to the extremity of a tube, so as to have the axis of the tube inclined at an angle of 35° 3′ to the perpendicular (or 54° 57′ to the plate) in the plane of the section A; then directing the axis of the tube to the centre of the dark spot, or the reflecting surface, it will be seen to continue dark, and remain so while the tube makes a complete revolution on its axis. Now, this could not be if the mica exercised any disturbing power on the plane of polarization. Hence, we conclude, that the two lines in question possess this remarkable property, *viz.* that *whatever be the plane of polarization of a ray incident along either of them, it remains unaltered after transmission.* For, although in the experiment above described, the plane of polarization remained fixed, and that of incidence was made to revolve, it is obvious that the reverse process would come to the very same thing.

890. Now, this character belongs to no other lines, however chosen, with respect to the plate. If we fix the plate on the end of the tube at any other angle, or in any other plane with respect to the axis of the latter, although *two* positions in the rotation of the tube will always be found where the disappearance of the transmitted ray takes place, in no other case but that of the two lines in question will this disappearance be total, or nearly so, in *all* points of its revolution.

891. Position of the optic axes in mi

The refracting index of mica being 1.500, an angle of incidence of 35° 3′ corresponds to one of refraction = 22° 31′. Hence, the position of the lines *within* the mica corresponding to these external lines is 22½° inclined to the perpendicular, and the angle included between them 45°. These, then, are *axes* within the crystal, bearing a determinate relation to its molecules. Dr. Brewster has termed them axes of no polarization, a long name. M. Fresnel, and others, have used the phrase optic axes, to which we shall adhere. As this term has before been applied to the "axes of no double refraction," we must anticipate so far as to advertise the reader that these, and the "axes of no polarization," are in all cases identical.

892 The polarized rings about the optic axes. General description of their phenomena. Fig. 176.

Having, by the criteria above described, determined the principal section, and ascertained the situation of the optic axes of the mica plate under examination, let the plate be inclined to the polarized beam, so that the latter shall be transmitted along the optic axes, the principal section A making an angle of 45° with the plane of polarization; and let the eye (still armed with the tourmaline plate, with its axis vertical) be applied close to the mica. A splendid phenomenon will then be seen. The black point corresponding to the direction of the optic axis will be seen to be surrounded with a set of broad, vivid, coloured rings, of an elliptic, or, at least, oval form, divided into two unequal portions by a black band somewhat curved, as represented in fig. 176. This band passes through the *pole*, or angular situation of the optic axis, about which the rings are formed as a centre. Its convexity is turned towards the direction of the other axis, and on that side the rings are also broader. If, now, the other axis be brought into a similar position, a phenomenon exactly similar will be seen surrounding its place, as a pole. If the mica plate be very thick, these two systems of rings appear wholly detached from, and independent of, each other, and the rings themselves are narrow and close; but if thin (as a 30th or 40th of an inch) the individual rings are much broader, and especially so in the interval between the poles, so as to unite and run together, losing altogether their elliptic appearance, and dilating towards the middle (or in the direction of a perpendicular to the plate) into a broad coloured space, beyond which the rings are no longer formed about each pole separately, but assume the form of reentering curves, embracing and including both poles. Their nature will presently be stated more at large.

If, preserving the same inclination of the mica plate to the visual ray, it be turned about it as an axis, the black band passing through the pole will shift its place, and revolve as it were on the pole as a centre with double the angular velocity, so as to obliterate in succession every part of the rings. When the plate has made 45° of its revolution, so as to bring its principal section into the plane of polarization of the incident beam, this band also coincides in direction with that plane, and is then visibly prolonged, so as to meet that belonging to the set of rings about the other pole; and is crossed at the middle point between the poles by another dark space perpendicular to it, or in the plane of the section B, presenting the appearance in fig. 177.

893. Further particulars. Fig. 177.

894. Other modes of exhibiting these phenomena.

These phenomena, if a tourmaline be not at hand, may be viewed, (somewhat less commodiously, unless the mica plate be of considerable size,) by using in its place the reflector figured in fig. 170, or by a pile of glass plates interposed obliquely between the eye and the mica. In this manner of observing them, the colours are surprisingly vivid, no part of the red and violet rays being absorbed more than the rest; whereas the tourmalines generally exert a considerable absorbing energy on these rays in preference to the rest, and thus the contrast of colours is materially impaired. On the other hand, however, from the greater homogeneity of the transmitted light, the rings are more numerous and better defined; and in this respect the phenomenon is greatly improved by the use of homogeneous light.

895. We have taken mica as being a crystallized body very easily obtained of large size, and presenting its axes readily, and without the necessity of artificial sections. It is thus admirably adapted for obtaining a general rough view of the phenomena, preparatory to a nicer examination. From the wide interval between its axes, however, and the considerable breadth of its rings, it is less adapted, when employed as above stated, to give a clear conception of the complicated changes which the rings undergo, on a variation of circumstances. For this reason we shall now describe another and much more commodious mode of examining the systems of polarized rings presented by crystals in general, which has the advantage of bringing the laws of their phenomena so evidently under our eyes as to make their investigation almost a matter of inspection.

896. General principle of methods of viewing the rings.

It is evident, that when we apply the eye close to, or very near a plate of mica, or other body, and view, beyond it, a considerable extent of illuminated surface, each point of that surface will be seen by means of a ray which has penetrated the plate in a different direction with respect to the axes of its molecules; so that we may consider the eye as in the centre of a spherical surface from all points of which rays are sent to it, modified according to the state of primitive polarization, and the influence of the peculiar energies of the medium, corresponding to the direction in which they traverse it, and the thickness of the plate *in that direction.*

Periscopic tourmaline apparatus described. Fig. 178.

Any means, therefore, by which we can admit into the eye through the plate and tourmaline a cone of rays nearly or completely polarized in one general direction, or according to any regular law, will afford a sight of the rings; and therefore exhibit, at a single view, a synopsis, as it were, of the modifications impressed on an infinite number of rays so polarized traversing the plate in all directions. The property of the tourmaline so often referred to puts it in our power to perform this in a very elegant and convenient manner, by the aid of the little apparatus of which fig. 178 is a section. A B C D is a short cylinder of brass tube, the end of which, A C, is terminated by a brass plate, having an aperture *a b*, into which is set a tourmaline plate cut parallel to the axis: *h g i k* is another similar brass cylinder, provided with a similar aperture and a similar tourmaline plate G, and fitted into the former so as to allow of the one being freely turned round within the other by the milled edges B D, *h k*. A lens H of short focus, set in a proper cell, is screwed on in front of the tourmaline G, so as to have its focus a little behind its posterior surface, (that next the eye, O.) Between the two surfaces A C, *g i* is another short cylinder of thin tube *c d*, carrying a brass plate with an aperture somewhat narrower than those in which the tourmalines are set, and on which any crystallized plate F to be examined may be cemented with a little wax. This, with the cylinder to which it is fixed, is capable of being turned smoothly round within the cylinder A B C D by means of a small pin *e* passing through a slit *f* made in the side, and extended round so as to occupy about 120° of the circumference; by which a rotation to that extent may be communicated to the crystallized plate F in its own plane between the tourmaline plates. The pin *e* should screw into the ring *c d*, that it may be easily detached, and admit the ring and plate to be taken out for the convenience of fixing on it other crystals at pleasure.

897. Mode of action of this apparatus.

The use of the lens H is to disperse the incident light, and thus equalize the field of view when illuminated by any source of light, whether natural or artificial, as well as to prevent external objects being distinctly seen through it, which would distract the attention and otherwise interfere with the phenomena. The rays converged by the lens to a focus within the crystallized plate F, afterwards diverge and fall on the eye O, after traversing the plate in all directions within the limit of the field of view. As by this contrivance they pass through a very small portion of the crystal, there is the less chance of accidental irregularities in its structure disturbing the regular formation of the rings, since we have it in our power to select the most uniform portion of a large crystal. The rays, after passing through the lens, are all polarized by the tourmaline G, in planes parallel to its axis; and passing through the eye in this state, if the crystal F be not interposed, the rays will, or will not, penetrate the second tourmaline, according as its axis is parallel or perpendicular to that of the first. In consequence, when the cylinder carrying the former is turned round within that carrying the latter, the field of view is seen alternately bright and dark.

898. Selection of crystals.

When the crystallized substance F is interposed, provided it be so disposed that one or other of its optic axes is situated any where in the cone of rays refracted by the lens, so that one of them shall reach the eye by traversing the axis, the polarized rings are seen. If both the axes of the crystal (supposing it to have more than one) fall within the field, a set of rings will be seen round both, and may be studied at leisure. In order to bring the whole of their phenomena distinctly under view, it is requisite to select such crystals as have their axes not much inclined to each other, so as to allow the rings about both to be seen without the necessity of looking very obliquely into the apparatus. In mica the axes are rather too far removed for this. The best crystal we can select for the purpose is nitre.

899. Nitre, method of preparing and polishing it.

Nitre crystallizes in long, six-sided prisms, whose section, perpendicular to their sides, is the regular hexagon. They are generally very much interrupted in their structure; but by turning over a considerable quantity of the ordinary saltpetre of the shops, specimens are readily found which have perfectly transparent portions of some extent. Selecting one of these, cut it with a knife into a plate above a quarter of an inch thick, directly across the axis of the prism, and then grind it down on a broad, wet file, till it is reduced to about $\frac{1}{5}$th or $\frac{1}{8}$th inch in thickness; smooth the surfaces on a wet piece of emeried glass, and polish them on a piece of silk strained very tight over a strip of plate glass, and rubbed with a mixture of tallow and coleothar of vitriol. This operation requires practice. It cannot be effected unless the nitre be applied *wet*, and rubbed till quite dry, increasing the rapidity of the friction as the moisture evaporates. It must be performed in gloves, as the vapour from the fingers, as well as the slightest breath, dims the polished surface effectually. With these precautions a perfect vitreous polish is easily obtained. We may here remark, that hardly any two salts can be polished by the same process. Thus, Rochelle salt must be finished wet on the silk, and instantly transferred to soft bibulous linen, and rapidly rubbed dry. Experience alone can teach these peculiarities, and the contrivances (sometimes very strange ones) it is necessary to resort to for the purpose of obtaining good polished sections of soft crystals, especially of those easily soluble in water.

900. Rings exhibited by nitre. Fig. 179. Fig. 180. Fig. 181. Fig. 182.

The nitre thus polished on both its surfaces (which should be brought as near as possible to exact parallelism) is to be placed on the plate at F; and the tourmaline plates being then brought to have their axes at right angles to each other (which position should be marked by an index line on the cylinders) the eye applied at O, and the whole held up to a clear light, a double system of interrupted rings of the utmost neatness and beauty will be seen, as represented in fig. 179. If the crystallized plate be made to revolve in its own plane between the tourmalines (which both remain unmoved) the phenomena pass through a certain series of changes periodically, returning, at every 90° of rotation, to their original state. Fig. 180 represents their appearance when the rotation is just commenced; fig. 181, when the angle of rotation is 22½°, or 67½°; and fig. 182, when it equals 45°. When the tourmalines are also made to revolve on each other, other more complicated appearances are produced, of which more presently. We shall now, however, suppose them retained in the situation above mentioned, *i.e.* with their axes crossed at right angles, and proceed to study the following particulars:

1. The form and situation of the rings.
2. Their magnitudes in the same and different plates.
3. Their colours.
4. The intensity of the illumination in different parts of their periphery.

901. Situation of the axes in the crystal.

The situation of the rings is determined by the position of the principal section of the crystal, or by that of the optic axes within its substance. These in nitre lie in a plane parallel to the axis of the prisms, and perpendicular to one or other of its sides. It is no unusual thing to find crystals of this salt whose transverse section consists of distinct portions, in which the principal sections make angles of 60° with each other; indicating a composite or macled structure in the crystal itself. These portions are divided from each other by thin films, which exhibit the most singular phenomena by internal reflexion, on which this is not the place to enlarge. In an uninterrupted portion, however, the forms of the rings are as represented in the figures above referred to, their poles subtending at the eye an angle of about 8°. Now, it is to be remarked, that as the plate is turned round between the tourmalines, although the black hyperbolic curves passing through the poles shift their places upon the coloured lines, and in succession obliterate every part of them; forming, first, the black cross in fig. 179, by their union; then breaking up and separating laterally, as in fig. 180, and so on. Yet the rings themselves retain the same form and disposition about their poles, and, except in point of intensity, remain perfectly unaltered; their whole system turning uniformly round as the crystallized plate revolves, so as to preserve the same relations to the axes of its molecules. Hence we conclude, that the coloured rings are related to the optic axes of the crystal, according to laws dependent only on the nature of the crystal, and not at all on external circumstances, such as the plane of polarization of the incident light, &c.

902. Form of the rings, that of lemniscates. Fig. 183.

The general form of the rings, abstraction made of the black cross, is as represented in fig. 183. If we regard them all as varieties of one and the same geometrical curve, arising from the variation of a parameter in its equation, it will be evident that this equation must, in its most general form, represent a reentering symmetrical oval, which at first is uniformly concave, and surrounds both poles, as A; then flattens at the sides, and acquires points of contrary flexure, as B; then acquires a multiple point, as C; after which it breaks into two conjugate ovals D D, each surrounding one pole. This variation of form, as well as the general figure of the curves, bears a perfect resemblance to what obtains in the curve well known to geometers under the name of the *lemniscate*, whose general equation is

$$(x^2 + y^2 + a^2)^2 = a^2 (b^2 + 4 x^2),$$

when the parameter b gradually diminishes from infinity to zero; $2\,a$ representing the constant distance between the poles.

903. Verified by experiment.

The apparatus just described affords a ready and very accurate method of comparing the real form of the rings with this or any other proposed hypothesis. If fixed against an opening in the shutter of a darkened room, with the lens H outwards, and a beam of solar light be thrown on the latter, parallel to the axis of the apparatus, the whole system of rings will be seen finely projected against a screen held at a moderate distance from E. Now, if this screen be of good smooth paper tightly stretched on a frame, the outlines of the several rings may easily be traced with a pencil on it, and the poles being in like manner marked, we have a faithful representation of the rings, which may be compared at leisure with a system of lemniscates, or any other curve graphically constructed, so as to pass through points in them chosen where the tint is most decided. This has accordingly been done, and it has been found that lemniscates so constructed coincide throughout their whole extent, to minute precision, with the outlines of the rings so traced, the points graphically laid down falling on the pencilled outlines. The graphical construction of these curves is rendered easy by the well-known property of the lemniscate, in which the rectangle under two lines P A × P′ A drawn from the poles to any point A in the periphery is invariable throughout the whole curve. This is easily shown from the above equation, and the value of this constant rectangle in any one curve is represented by $a \times b$.

904. Variation of the parameter b in arithmetic progression from ring to ring.

When we shift from one ring to another, a remains the same, because the poles are the same for all. To determine the variation of b, let the rings be illuminated with homogeneous light, (or viewed through a red glass,) and outlined by projection, as above. Then, if we determine the actual value of $a\,b$ by measuring the lengths of two lines P A, P′ A drawn from P, P′ to any point of each curve; and, calculating their product, (to which $a\,b$ is equal,) it will be found that this product, and therefore the parameter b, *increases in the arithmetical progression* 0, 1, 2, 3, 4, *&c. for the several dark intervals of the rings beginning at the pole*, and in the progression $\frac{1}{2}$, $\frac{3}{2}$, $\frac{5}{2}$, &c. for the brightest intermediate spaces. To ensure accuracy, the mean of a number of values of P A × P′ A, at different points of the periphery, may be taken to obviate the effect of any imperfection in the crystal.

905. Effect of varying the thickness of the plate.

This, then, is the law of the magnitudes of the successive rings formed by one and the same plate. But if we determine the value of the same product for plates of nitre similarly cut, but of different thicknesses, or of the same reduced in thickness by grinding, it will be found to vary inversely as the thickness of the plate, *cæteris paribus*.

906. The colours of the rings.

The colours of the polarized rings bear a great analogy to those reflected by thin plates of air, and in most crystals would be precisely similar to them but for a cause presently to be noticed. In the situation of the tourmaline plates here supposed (crossed at right angles) they are those of the reflected rings, beginning with a black centre, at the pole. If examined in the situation of fig. 179, and traced in a line from either pole cutting across the whole system, at right angles to the line joining the poles, they will almost precisely follow the Newtonian scale of tints. For the present we will suppose that they do so in all directions. It is evident, then, that each particular tint (as the bright green of the third order, for instance) will be disposed in the form of a lemniscate, and will have its own particular value of the product $a\,b$. The tint, then, may be said to be corresponding to,—dependent on,—or, if we will, *measured by* $a\,b$. In conformity with this language the coloured curves have been termed, and not inaptly, *isochromatic lines*. Now, in the colours of thin plates, we have seen that these tints arise from a law of periodicity to which each homogeneous ray is subject; and that (without entering at this moment into the cause of such periods) the successive maxima and minima of each particular coloured ray passed through, in the scale of tints, correspond to successive multiples by $\frac{1}{2}$, $\frac{2}{2}$, $\frac{3}{2}$, $\frac{4}{2}$, &c. of the period peculiar to that colour. In the colours of thin plates, the quantity which determines the number of periods is the thickness of the plate of air, or other medium traversed; and the number of times a certain standard thickness peculiar to each ray is contained therein, determines the number of periods, or parts of a period, passed through. In the colours, and in the case now under consideration, the number of periods is proportional to the product $(\theta \times \theta')$ of the distances from either pole, for one and the same thickness of plate,—and for different plates to t the thickness,—and, therefore, generally, to $\theta \times \theta' \times t$, provided we neglect the effect of the inclination of the ray in increasing the length of the path of the rays within the crystal, or regard the whole system of rings as confined within very narrow limits of incidence.

Numerical measure of the tint of any isochromatic line.

Law of periodicity.

907. Transition from nitre to other crystals whose axes are farther asunder.

This condition obtains in the case here considered, because of the proximity of the axes in nitre to each other and to the perpendicular to the surfaces of the plate. But in crystals such as mica, or others where they are still wider asunder, it is not so; and the projection of the isochromatic curves on a plane surface will deviate materially from their true form, which ought to be regarded as delineated on a sphere having the eye, or rather a point within the crystal, for a centre. In such a case, it might be expected that the usual transition from the arc to its sine should take place; and that, instead of supposing the tint, or value of $a\,b$, to be proportional simply to $\theta \times \theta' \times t$, (putting $\theta = \mathrm{A\,P}$, and $\theta' = \mathrm{A\,P'}$,) we ought to have it proportional to $\sin\theta \times \sin\theta' \times$ length of the path of the ray within the crystal. Now (putting ρ for the angle of refraction, and t for the thickness of the plate) we have $t \,.\, \sec\rho =$ length of the ray's path within the crystal. If, then, we put n for the number of periods corresponding to the tint $a\,b$ for the ray in question, and suppose $h = \frac{a\,b}{n}$, or the unit whose multiples determine the order of the rings, we shall have

General expression for the tint polarized by any crystallized plate.

$$n = \frac{a\,b}{h} = \frac{t}{h} \,.\, \sin\theta \,.\, \sin\theta' \,.\, \sec\rho, \qquad (a)$$

and

$$h = \frac{t}{n \,.\, \cos\rho} \,.\, \sin\theta \,.\, \sin\theta'. \qquad (b)$$

If, then, the suppositions made be correct, we ought to have the function on the right hand side of this last equation invariable, in whatever direction the ray penetrates the crystallized plate, and whatever be the order of the tint denoted by n. We shall here relate only one experiment, to show how very precisely the agreement of this conclusion with fact is sustained.

908. Experiment verifying this law.

A ray of light was polarized by reflexion at a plate of perfectly plane glass, and transmitted through a plate of mica, having its principal section 45° inclined to the plane of primitive polarization, and the mica plate made to revolve in the plane of its principal section about an axis at right angles thereto, (or about the axis B, Art. 885.) In this state of things, if viewed through a tourmaline as above described, or by other more refined means presently to be noticed, the succession of tints exhibited by the mica was that of a section of the rings in fig. 182, made by a line drawn through both the poles. To render the observation definite, a red glass was interposed so as to reduce the rings to a succession of red and black bands, and the angles of incidence corresponding to the maxima and minima of the several rings very accurately measured. These are set down in *Col.* 2 of the following table. *Col.* 1 contains the values of n, 0 corresponding to the pole, $\frac{1}{2}$ to the first maximum, 1 to the first minimum, $1\frac{1}{2}$ to the second maximum, and so on. The third column contains the angles of refraction computed for an index 1.500; the fourth and fifth, those of θ and θ'; the sixth, those of h deduced from the above equation, and which ought to be constant. The excesses above the mean are stated in the last column, and show how very closely that equation represents the fact. The thickness of the mica was 0.023078 inches $= t$.

Values of n.	Angles of incidence.	Angles of refraction $= \rho$.	Values of θ.	Values of θ'.	Values of h.	Excesses above the mean.
0.0	35° 3′ 30″	22°31′ 0″	0° 0′ 0″	45° 2′ 0″		
0.5	32 55 20	21 14 40	1 16 20	43 45 40	0.032952	− 0.000195
1.0	30 34 40	19 49 30	2 41 30	42 20 30	0.033622	+ 0.000475
1.5	28 15 40	18 24 0	4 7 0	40 55 0	0.033035	− 0.000112
2.0	25 34 20	16 43 30	5 47 30	39 14 30	0.033327	+ 0.000180
2.5	22 46 20	14 57 15	7 33 45	37 28 15	0.033148	+ 0.000001
3.0	19 35 40	12 55 10	9 35 50	35 26 10	0.033058	− 0.000089
3.5	15 48 40	10 27 50	12 3 10	32 58 50	0.033026	− 0.000121
4.0	10 48 50	7 11 10	15 19 50	29 42 10	0.033010	− 0.000137

909. General establishment of the law.

Proceeding thus, and measuring across the system of rings in all directions for plates of various crystals and of all thicknesses, it has been ascertained, as a general fact, that in all substances which possess the property of developing periodical colours by exposure to polarized light in the manner described, the tint (n), or rather the number of periods and parts of a period corresponding, in the case of a ray of given refrangibility, to a thickness t, an angle of refraction ρ, and a position within the crystal, making angles θ and θ' with the optic axes, is represented by the equation

$$n = \frac{t \,.\, \sec \rho}{h} \times \sin \theta \,.\, \sin \theta',$$

Case of a crystal formed into a sphere.

h being a constant depending only on the nature of the crystal and the ray. Were the crystal of a spherical form, instead of a parallel plate, $t \,.\, \sec \rho$, which represents the path traversed by the ray within it, must be replaced by a constant equal to the diameter of the sphere, and in that case the tint would be simply proportional to the product of the sines of θ and θ'. This elegant law is due to M. Biot, though it is to Dr. Brewster's indefatigable and widely extended research that we owe the general developement of the splendid phenomena of the polarized rings in biaxal crystals. It appears, then, from this, that if, on the surface of a sphere formed of any crystal, curves analogous to the lemniscate, or having $\sin \theta \times \sin \theta'$ constant for each curve, and varying in arithmetical progression from curve to curve, be described,—then, if the sphere be turned about its centre in a polarized beam, as above described, the tint polarized at every point of each curve will be the same, and in passing from curve to curve will obey the law of periodicity proper to the crystal.

910. Methods of viewing the rings at great obliquities.

There is hardly any character in which crystals differ more widely than in the angular separation of their optic axes, as the table annexed to the end of this article will show. This, while it affords most valuable criteria to the chemist and mineralogist, in discriminating substances and pointing out differences of structure and composition which would otherwise have passed unnoticed, renders the investigation of their phenomena difficult, since it is frequently impossible, by any contrivance, to bring both the axes under view at once; and necessitates a variety of artifices to obtain a sight of the rings about both. It is often very easy to cut and polish crystallized bodies in some directions, and very difficult in others. However, by immersing plates of them in oil, and turning them round on different axes, or by cementing on their opposite sides prisms of equal refracting angles oppositely placed, as in fig. 184, we may look through them at much greater obliquities than without such aid; and thus, by increasing the range of vision to nearly a hemisphere, avoid in most instances the necessity of cutting them in different directions.

Fig. 184.

911. Rings in crystals with one axis. Fig. 185.

When the two axes coalesce, or the crystal becomes uniaxal, the lemniscates become circles; and the black hyperbolic lines, passing through the poles, resolve themselves into straight lines at right angles to each other, forming a black cross passing through the centre of the rings, as in fig. 185. In this case the tint is represented by $t \,.\, \sin \theta^2$; and in the case of plates, where t, the thickness, is considerable, or where, from the otherwise peculiar nature of the substance the rings are of small dimensions, θ is small, and therefore proportional to its sine; so that in passing from ring to ring θ^2 increases in arithmetical progression. Hence the diameters of the rings are as the square roots of the numbers 0, 1, 2, 3, &c.; and therefore their system is similar, with the exception of the black cross, to the rings seen between object-glasses. Carbonate of lime cut into a plate at right angles to the axis of its primitive rhomboid, exhibits this phenomenon with the utmost beauty. The most familiar instance, however, may be found in a sheet of clear ice about an inch thick frozen in still weather. A pane of window-glass, or a polished table to polarize the light, a sheet of ice freshly taken up in winter

Familiarly shown in ice.

produce the rings, and a broken fragment of plate glass to place near the eye as a reflector, are all the apparatus required to produce one of the most splendid of optical exhibitions.

912. Analogy between the colours of the polarized rings and those produced by the law of interference

If θ be not very small, the measure of the tint, instead of $t \,.\, \sin \theta^2$, is $t \,.\, \sec \rho \,.\, \sin \theta^2$. We have seen that in uniaxal crystals, $\sin \theta^2$ is proportional to the difference of the squares of the velocities v and v' of the ordinary and extraordinary ray, or to $v'^2 - v^2$. Now, if we denote by τ and τ' the times taken by these two rays to traverse the plate, we have $v = \frac{t \,.\, \sec \rho}{\tau}$ and $v' = \frac{t \,.\, \sec \rho}{\tau'}$; therefore $t \,.\, \sec \,.\, \rho \sin \theta^2$ is proportional to

$$(t \,.\, \sec \rho)^3 \times \left(\frac{1}{\tau'^2} - \frac{1}{\tau^2}\right), \text{ that is, to } \frac{(\tau + \tau')(\tau - \tau')}{(\tau \tau')^2} \,.\, (t \sec \rho)^3,$$

or (which is the same thing) to $(v + v') \,.\, v v' (\tau - \tau')$. But, neglecting the squares of very small quantities, of the order $v' - v$ and $\tau - \tau'$, for such they are in the immediate neighbourhood of the axis, the factors $v + v'$ and $v v'$ are constant; so that the tint is simply proportional to $\tau - \tau'$, the difference of times occupied by the two rays in traversing the plate; or *the interval of retardation* of the slower ray on the quicker. This very remarkable analogy between the tints in question and those arising from the law of interferences, was first perceived by Dr. Young; and, assisted by a property of polarized light soon to be mentioned, discovered by Messrs. Arago and Fresnel, leads to a simple and beautiful explanation of all the phenomena which form the subject of this section, and of which more in its proper place.

913. Circumstances which distort the rings.

The forms of the rings are such as we have described, only in regular and perfect crystals; every thing which disturbs this regularity, distorts their form. Some crystals are very liable to such disturbances, either arising from an imperfect state of equilibrium, or a state of strain in which the molecules are retained, or to actual interruptions in their structure. Thus, specimens of quartz and beryl are occasionally met with, in which the single axis usually seen is very distinctly separated into two, the rings instead of circles have oval forms, and the black cross (which in cases of a well developed single axis remains quite unchanged during the rotation of the crystallized plate in its own plane) breaks into curves convex towards each other, but almost in contact at their vertices, at every quarter revolution. Cases of interruption occur in carbonate of lime very commonly, and in muriacite perpetually; and the effects produced by them on the configurations of the rings rank among the most curious and beautiful of optical phenomena. They have not, however, been anywhere described, and our limits will not allow us to make this article a vehicle for their description.

914. Colours of the rays.

The form of the rings being, then, considered, let us next inquire more minutely into their colours. These being all composite, and arising from the superposition on each other of systems of rings formed by each homogeneous ray, we can obtain a knowledge of their constitution only by examining the rings in homogeneous light. This is easy, for we have only to illuminate the apparatus described above by homogeneous light of all degrees of refrangibility from red to violet, by passing a prismatic spectrum from one end to the other over the illuminating lens H, the eye being applied as usual at O, and observe the changes which take place in the rings, in passing from one coloured illumination to another; and, if necessary, measure their dimensions. This is readily done, either by projecting them on a screen in a darkened room, as described in Art. 903, or by detaching the lens H, fig. 178, and simply looking through the apparatus at a sheet of white paper strongly illuminated by the rays of a prismatic spectrum, where the rings will appear as if depicted on the paper, and their outlines easily marked, or their diameters measured. The following are the general facts which may thus be readily verified.

915. In crystals with one axis. Deviations from Newton's scale. In the apophyllite.

First, in the case of crystals with a single axis, the rings remain circular, and their centres are coincident for all the coloured rays, but their dimensions vary. In the generality of such crystals, their diameters for different refrangibilities follow nearly the law of the Newtonian rings, when viewed in similar illuminations; their squares (or rather the squares of their sines) being proportional, or nearly so, to the lengths of the fits, or of the undulations of the rays forming them. This law, however, is very far from universal; and in certain crystals is altogether subverted. Thus, in the most common variety of apophyllite, (from Cipit, in the Tyrol,—not from Fassa, as is commonly stated,) the diameters of the rings are nearly alike for all colours, those of the green rings being a very little less; those formed by rays at the confines of the blue and indigo exactly equal, and those of violet rays a little greater than the red rings. It is obvious, that were the rings of all colours exactly equal, the system resulting from their superposition would be simple alternations of perfect black and white, continued *ad infinitum*. In the case in question, so near an approach to equality subsists, that the rings in a tourmaline apparatus appear merely black and white, and are extremely numerous, no less than thirty-five having been counted, and many of those too close for counting being visible in a thick specimen.

916. When examined more delicately, colours are, however, distinguished, and are in perfect conformity with the law stated, being for the first four orders as follow:

First order. Black, greenish white, bright white, purplish white, sombre violet blue.

Second order. Violet almost black, pale yellow green, greenish white, white, purplish white, obscure indigo inclining to purple.

Third order. Sombre violet, tolerable yellow green, yellowish white, white, pale purple, sombre indigo.

Fourth order. Sombre violet, livid grey, yellow green, pale yellowish white, white, purple, very sombre indigo, &c.

917 Carbonate of lime, beryl, ice, and tourmaline (when limpid) are instances of uniaxal crystals, in whose rings the Newtonian scale of tints is almost exactly imitated; and, consequently, the intervals of retardation of the ordinary and extraordinary rays of any colour on one another, are proportional to the lengths of their undulations. On the other hand, in the hyposulphate of lime, we are furnished with an instance of more rapid

In hyposulphate of lime.

degradation of tints, and therefore of a more rapid variation of the interval just mentioned. The following was the scale of colour of the rings observed in this remarkable crystal:

First order. Black, very faint sky blue, pretty strong sky blue, very light bluish white, white, yellowish white, bright straw colour, yellow, orange yellow, fine pink, sombre pink.

Second order. Purple, blue, bright greenish blue, splendid green, light green, greenish white, ruddy white, pink, fine rose red.

Third order. Dull purple, pale blue, green blue, white, pink.

Fourth order. Very pale purple, very light blue, white, almost imperceptible pink.

After which the succession of colours was no longer distinguishable.

918. Other remarkable cases of deviation.

A degradation still more rapid has been observed in certain rare varieties of uniaxal apophyllite, accompanied with remarkable and instructive phenomena. In these, the diameters of the rings (instead of diminishing as the refrangibility of the light of which they are formed increases) increase with great rapidity, and actually become infinite for rays of intermediate refrangibility; after which they again become finite, and continue to contract up to the violet end of the spectrum, where, however, they are still considerably larger than in the red rays. In consequence of this singularity, their colours when illuminated with white light furnish examples of a complete inversion of Newton's scale of tints. The following were the tints exhibited by two varieties of the mineral in question, in one of which the critical point where the rings become infinite took place in the indigo, and in the other in the yellow rays. In the former they were

First order. Black, sombre red, orange, yellow, green, greenish blue, sombre and dirty blue.

Second order. Dull purple, pink, ruddy pink, pink yellow, pale yellow (almost white,) bluish green, dull pale blue.

Third order. Very dilute purple, pale pink, white, very pale blue.

In the latter variety, the tints were

First and only order. Black, sombre indigo, indigo inclining to purple, pale lilac purple, very pale reddish purple, pale rose red, white, white with a hardly perceptible tinge of green.

919. Relation between the diameters of the rings and the doubly refractive energy.

The *doubly refracting energy* of a crystal may be not improperly measured by the difference of the squares of the velocities of an ordinary and extraordinary ray similarly situated with respect to the axes; but as this difference, for rays variously situated in one and the same crystal, is proportional to $\sin\theta^2$, or in biaxal crystals to $\sin\theta \,.\, \sin\theta'$, the *intrinsic double refractive energy* of any crystal may be represented by

$$e = \frac{v^2 - v'^2}{\sin\theta \,.\, \sin\theta'}; \qquad (c)$$

regarding this henceforth as the *definition* of this energy, we have, in uniaxal crystals, $e = \frac{v^2 - v'^2}{\sin\theta^2}$, and this will evidently measure the actual amount of separation of two such rays when emergent from the crystal. If in this we put for v and v' their equals $\frac{t \,.\, \sec\rho}{\tau}$ and $\frac{t \,.\, \sec\rho}{\tau'}$, we shall have, after reduction,

$$v^2 - v'^2 = v\,v'\,(v + v') \,.\, \frac{\tau' - \tau}{t \,.\, \sec\rho}. \qquad (c)$$

Case of crystals at once attractive, repulsive, and neutral.

In a parallel plate, perpendicular to the axis and in the immediate vicinity of the axis, v' and $\sec\rho$ may be regarded as constant, and $v^2 - v'^2$ is proportional to $\tau' - \tau$, the interval of retardation of one ray on the other, to which the tint in white light and the number of periods and parts of a period in homogeneous light (to which, for brevity, we will continue to extend the term *tint*) are proportional. We see, then, that in such cases the intrinsic double refracting energy is directly as the tint polarized, and inversely as $\sin\theta^2$, and therefore also inversely as the squares of the diameters of the rings. As the rings increase in magnitude, then, *cæteris paribus*, the double refractive energy diminishes; and hence a very curious consequence follows, *viz.* that in the two cases last mentioned it vanishes altogether for those colours where the rings are infinite; in other words, that although the crystal be doubly refractive for all the other coloured rays, there is one particular ray in the spectrum (*viz.* the indigo in the former, and the yellow in the latter case) with respect to which its refraction is single. In the passage through infinity, there is generally a change of sign. In the instances in question this change takes place in the value of e or $v^2 - v'^2$, which passes from negative to positive. And the spheroid of double refraction changes its character accordingly from oblate to prolate, passing through the sphere as its intermediate state. The manner in which this may be recognised, without actually measuring, or even perceiving its double refraction, will be explained further on.

920. Application to biaxal crystals.

For crystals with two axes we have only, at present, the ground of analogy to go upon in applying the above formula and phraseology to their phenomena. The general fact of an intimate connection of the double refracting energy with the dimensions of the rings, is indeed easily made out; for it is a fact easily verified by experiment, that *all crystals, whether with one or two axes, in which the rings or lemniscates formed are of small magnitude in respect of the thickness of the plate producing them, are powerfully double refractive, and vice versâ;* and that, generally speaking, the separation of the ordinary and extraordinary pencils is, *cæteris paribus,* greater in proportion as the rings are more close and crowded round their poles. In uniaxal crystals, in which the laws of double refraction are comparatively simple, there is little difficulty in submitting the point to the test of direct experiment and exact measurement, and it is found to be completely verified. In biaxal, however, such precise and direct comparison is more difficult, and calls for a knowledge of the general laws of double refraction. The analogy, however, supported by the general coincidence above mentioned, is too strong to be refused; and, as we advance, will be found to gain strength with every step.

section, the nearest approximation to Newton's scale of colours is obtained by assuming, for the origin of the scale, not the poles themselves, but other points (which have been called *virtual poles*, though improperly) lying either between or beyond them, according to the crystal examined, and at a distance from them, invariable for each species of crystal, whatever be the thickness of the plate. In consequence, the poles themselves are not absolutely black, but tinged with colour; and their tint descends in the scale as the thickness of the plate increases, and as, in consequence, one, two, or more orders of rings intervene between them and the points from which the scale originates. These points are observed to lie between the poles in all crystals which have the blue axes nearer than the red, such as Rochelle salt, borax, mica, sulphate of magnesia, topaz; and beyond them for those in which the red axes include a less angle than the blue, as sulphate of baryta, nitre, arragonite, sugar, hyposulphite of strontia; and this fact, as well as the constancy of their distance from the poles when the thickness of the plate is varied, renders their origin evident. In fact, since the violet rings are smaller than the red, if the centre about which the former are described, instead of being coincident with that of the latter, be shifted in either direction, carrying its rings with it, some one of the violet rings will necessarily be brought up to, and fall upon a red ring of the same order; and the same holding good with the intermediate rays, provided the law which determines the separation of the different coloured axes be not very different from that which regulates the dimensions of the rings of corresponding colours, the point of coincidence of a red and violet ring of the same order will be nearly that of a red and green, or any intermediate colour. The tint, then, at this point will be either absolutely black, (if they be dark rings which are thus brought to coincidence,) or white, if bright; and from this point the tints will reckon either way with more or less exactness, according to the same scale which would have held good had the points of coincidence been the poles themselves. Should, however, the two laws above mentioned differ very widely, an uncorrected colour will be left at the point of nearest compensation, just as happens when two prisms whose scales of dispersion are dissimilar are employed to achromatise each other. To what an extent the disturbance of the Newtonian scale of tints may be carried by this and the other causes already explained, the reader may see by turning to the table of tints exhibited by Rochelle salt in *Phil. Trans.* 1820, part i.

925. Two suppositions as to the mode of action of crystals in forming the rings. We come next to consider the law of the intensity of the illumination of the rings in different parts of their periphery; but this part of their theory will require us to enter more fundamentally into the mode in which their formation is effected, and to examine what modifications the polarized ray incident on the crystallized plate undergoes in its passage through it, so as to present phenomena so totally different from those which it would have offered without such intervention. It is evident then, first, that since the ray, if not acted on by the plate, would have been entirely stopped by the second tourmaline, but, when so acted on, is partially transmitted so as to exhibit coloured appearances of certain regular forms; that the crystallized plate must have either destroyed altogether the polarization of that part of the light which is thereby enabled to penetrate the second tourmaline, or, if not, must have altered its plane of polarization, so as to allow of a partial transmission. Between these two suppositions it is not difficult to decide.

Doctrine of polarization considered. Were the portion of light which passes through the second tourmaline and forms the rings wholly *depolarized*, that is, restored to its original state of natural light, since the remainder, its complement to unity, which continues to be stopped by the tourmaline, retains its state of polarization unaltered, it is evident, that each ray at leaving the crystallized plate would be composed of two portions, one unpolarized ($= A$), the other ($= 1 - A$) polarized. Of these, the half only of the first ($\frac{1}{2} A$) would be transmitted by the second tourmaline. Now, suppose this to be turned round in its own plane through any angle ($= a$) from its original position, then the unpolarized portion will continue to be half transmitted; and the polarized, being now partially also transmitted, (in the ratio of $\sin^2 a : 1$,) will mix with it, so that the compound beam will be represented by

$$\tfrac{1}{2} A + (1 - A) \,.\, \sin^2 a = \sin^2 a + \frac{A}{2} \,.\, \cos 2\, a.$$

Now, if we suppose a to pass in succession through the values 0, 45°, 90°, 135°, 180°, &c., this will become respectively $\frac{1}{2}$ A, $\frac{1}{2}$, 1 − $\frac{1}{2}$ A, $\frac{1}{2}$, $\frac{1}{2}$ A, &c. Hence, at every quarter revolution the tints ought to change from those of the reflected rings to those of the transmitted, the complements of the former to white light; and at every half quarter revolution no rings at all should be seen, but merely an uniformly bright field illuminated with half the intensity of light which would be seen were the second tourmaline altogether removed.

926. Phenomena of the complementary rings. Fig. 188. But the phenomena which actually take place are very different. At the alternate quadrants, it is true, the complementary rings are produced, and the appearance is as represented in fig. 188. The black cross is seen changed into a white one; the dark parts of the rings are become the bright ones; the green is changed into red, and the red into green, &c.; so that if we were to examine no farther, the fact would appear to agree with the hypothesis. But in the intermediate half quadrants, this agreement no longer subsists. Instead of a uniformly illuminated field, a compound set of rings, consisting of eight compartments, alternately occupied by the primary and complementary set, is seen, presenting the appearance of fig. 191, and which is further described in Art. 935.

927. Hypothesis of a change of polarization. The phenomena then are incompatible with the idea of *depolarization*. It remains to examine what account can be given of them on the supposition of a *change* of polarization operated by the plate; and here we must remark *in limine*, that this cause is what in Newton's language would be termed a *vera causa*, a cause actually in existence; for we have already seen that every ray, whether polarized or not, traversing a double refracting medium in any direction, except precisely along its axis, is resolved into two, polarized in opposite planes. When the incident ray is polarized, these portions (generally speaking) differ in intensity, and though, owing to the parallelism of the plate they emerge superposed, their polarization is not the less real, and either of them may be suppressed, and the other suffered to pass, by receiving them on a tourmaline properly situated. This is so far

Use of this apparatus.

uniaxal crystal, having its axis perpendicular to the plane of the plate,) is to be placed on the swing frame across the aperture, and being adjusted so as to have its axis directed precisely along the axis of the tube when the vernier of D reads off zero, which is readily performed by the various adjustments belonging to the frame, as above described, the instrument is ready for use. The attainment of this condition may be known by turning the tube C on the tube A B as an axis, when the extraordinary image of the aperture P, seen through a doubly refracting prism, ought to vanish in the zero position of the vernier K, and not be restored in any part of the rotation of the tube; for it is manifest, that the axis is the only line to which this property belongs, or to which all the rings are symmetrical. It is then evident, that, however the parts of the apparatus be disposed, 1st, the reading off of the vernier D will give the angle of incidence on the plate; 2d, that of the vernier B, the angle made by the *plane of incidence* with the *plane of primitive polarization;* 3d, that of the vernier *c* will indicate the angle included by any assumed section of the crystallized plate perpendicular to its plane with the plane of incidence; and, lastly, that the reading of the vernier K will give the angle between the plane of primitive polarization and the principal section of the doubly refracting prism.

931. Its application to the phenomena of the rings of one axis. Fig. 188.

Suppose now we adjust the vernier B to zero, it will then be found, that however the plate E be situated, or whatever be the incidence of the ray, only the ordinary image will be seen (being white,) the extraordinary being extinguished (or black.) In this case we traverse the system of rings in the direction of the vertical arm of the black cross, fig. 185, of the primary, and the white one of the complementary set, see fig. 188. The phenomena are the same if we set the vernier B to 90°, and then turn the frame E on its axis, thus varying the incidence in a plane at right angles to that of primitive polarization, or, which comes to the same thing, traversing the rings along the horizontal arm of the black and white crosses. In intermediate positions of the vernier B, we traverse the rings along a diameter, making an angle with vertical equal to the reading of the vernier. In this case the two images of P are both visible, and finely coloured; the *extraordinary* image presenting the tint of the primary rings due to the particular angle of incidence indicated by the vernier D; the *ordinary*, that of the complementary system corresponding to the same angle. The colours of the two images are thus seen in circumstances the most favourable, being finely contrasted and brought side by side, so as to be capable of the nicest comparison. It is when the vernier D reads 45°, or the plane of incidence is 45°, inclined to that of primitive polarization, that the contrast of the two images is at its maximum, the tints in the extraordinary image being then most vivid, and those in the ordinary free from any mixture of white light. In general, if A represent the light of the extraordinary image in the position above mentioned, and a the angle read off on the vernier B, in any other position of the plane of incidence, the two images in this new position (for the same angle of incidence) will be represented respectively by

$$A\,.\,(\sin 2\,a)^2, \text{ and } 1 - A\,(\sin 2\,a)^2$$

that is, by

$$A\,.\,(\sin 2\,a)^2, \text{ and } (\cos 2\,a)^2 + (1 - A)\,.\,(\sin 2\,a)^2.$$

The former of these expressions indicates a ray whose tint is represented by A, and its intensity by $(\sin 2\,a)^2$; the latter, a complementary tint $1 - A$ of the same intensity, diluted with a quantity of white light, whose intensity is represented by $(\cos 2\,a)^2$.

932. Agreement of the formulæ with M. Biot's hypothesis.

These expressions represent with great fidelity the tints of both images, the intensity of the extraordinary, and the apparent degree of dilution of the ordinary one; and since a ray A polarized in a plane making an angle $2\,a$ with the principal section of the doubly refracting prism, would be divided between the extraordinary and ordinary image in the ratio of $(\sin 2\,a)^2 : (\cos 2\,a)^2$, it follows, that if we regard the pencil at its emergence from the crystallized plate as composed of two portions, one $(= A)$ polarized in the above named plane, the other $(= 1 - A)$ preserving its primitive polarization, the two pencils formed by the doubly refracting prism will be composed as follows:

	Extraordinary image.	Ordinary image.
1st. From the pencil A..........	$A\,(\sin 2\,a)^2$	$A\,.\,(\cos 2\,a)^2$
2d. From the pencil (1 − A)....	0	$1 - A$
Sum	$A\,(\sin 2\,a)^2$	$1 - A + A\,.\,\cos 2\,a^2$ $= 1 - A\,.\,(\sin 2\,a)^2$

Office of the doubly refracting prism or tourmaline.

which are identical with those above. Thus we see, that the facts are so far perfectly conformable to M. Biot's hypothesis of movable polarization, and that we are even necessitated to admit it, *provided we take it for granted, that the rings exist actually formed and superposed in the pencil emergent from the crystallized lamina, and that the office of the doubly refracting prism is merely to analyze the emergent pencil, and separate the two sets from each other.* But if the objection mentioned above against that doctrine be really well founded, this assumption cannot be correct, and we are then driven to conclude, that the doubly refracting prism, or tourmaline, or glass reflector, interposed between the eye and the crystallized plate, performs a more important office than merely to separate the tints already formed; and that, in fact, they are actually produced by its action,—the crystallized plate only preparing the rays for the process they are here finally to undergo.

933. To explain how this may be conceived to happen will form the object of another Section. Meanwhile we will here only add, that the transition from uniaxal to biaxal crystals is readily made. We have only to consider, that by varying the angle of incidence, (the line bisecting the angle between the optic axes being supposed perpendicular to the plane of the plate,) we cross the rings in a line passing through their centre of symmetry O, fig. 183, and making an angle with their principal diameter PP', equal to the angle read off on the vernier B, and that by turning the plate in its own plane, or varying the angle read off by the vernier c, we in effect make the system traversed pass through the successive states represented in fig. 179, 180, 181, 182, changing, not the tint, but the intensity of the extraordinary image.

934. Effect of turning the prism in its cell.

When the doubly refracting prism is turned in its cell, the tints grow more dilute, and when placed in an azimuth a, that is, when its principal section is placed in the plane of incidence, both images are colourless, but of unequal brightness. This accords with M. Biot's doctrine of movable polarization; for if we grant that the pencil A is polarized in a plane making an angle $2a$ with that of primitive polarization, it will make, now, an angle $= a$ with that of the principal section of the prism, and $A \,.\, (\sin a)^2$ will be that part of the extraordinary image arising from the pencil A; on the other hand, the pencil $1 - A$ retaining its original polarization, $(1 - A) \,.\, \sin a^2$ will be the portion of the extraordinary image produced by it in the new position of the prism, and the sum, or the whole image, will be simply $1 \times \sin a^2$, which being independent of A, or of the tint, indicates that the image is colourless. In the same manner it may be shown, that the ordinary image will equal $1 \times \cos a^2$, and their intensities will, therefore, be to each other as $\sin a^2$ to $\cos a^2$, and will be equal at 45° of azimuth; all which is conformable to fact.

935. Effect of turning the tourmalines about on each other. Fig. 191.

The motion of the prism in its cell corresponds to a rotation of the posterior tourmaline in its own plane in the tourmaline apparatus. The general appearance presented by the rings of a single axis, when this rotation is not a precise quadrant, is represented in fig. 191, and the succession of changes being as follows: At the first commencement of the rotation the arms of the black cross appear to dilate; they grow at the same time fainter, and segments of the complementary rings appear in them, whose bright intervals correspond to the dark ones of the primary set, their red to the green portions of that set, and *vice versâ*. The junction of the two sets is marked by a faint white or undecided tint. As the rotation proceeds, the primary segments contract in extent, and become more diluted with white, while the secondary extend, and grow more decided; at the same time the centre of the system grows gradually bright, and when the rotation has attained 90°, the whole has assumed the appearance in fig. 188. The phenomena are precisely analogous in the rings of biaxal crystals. The least deviation from exact rectangularity in the tourmalines gives rise to complementary segments in the dark hyperbolic curves answering to the arms of the black cross, and to a corresponding dilution and contraction of the primary segments, which at last disappear altogether in the undistinguishable whiteness of a pair of white hyperbolas precisely similar to the black ones of the primary rings in their perfect state.

936. Tints produced by very thin plates at great distances from the axes.

Hitherto we have considered the rings as so narrowed by the thickness of the plate, as to be all contracted within a compass round the poles which the eye can take in at once; but if the thickness be greatly diminished, this will no longer be the case; and, instead of rings of a distinguishable form, we shall see only broad bands of colour extending to great distances from the poles, and even visible when the axes themselves are so much inclined to the surfaces of the plate as to be quite out of sight; or even when the axes actually lie in the plane of the plate. This is the case with the laminæ into which sulphate of lime readily splits; the axes lie *in their plane*, so that to see the rings in them, we must form artificial surfaces perpendicular to the lamina, a difficult and troublesome operation, from the extreme softness and fissile nature of the substance. The phenomena of the colours of this crystal were early studied, and almost of necessity misconceived, till Dr. Brewster, by exhibiting the real axes, showed that they form only a particular case of the general phenomenon we have already dwelt on.

937. Phenomena of a single thin plate.

Adhering to the denominations employed in Art. 885—888, let us call the plane containing the two axes, *the section* A; that perpendicular to it, and passing through the line which bisects their *lesser* included angle, *the section* B; and that which similarly passes through the line bisecting their *greater* included angle, and is perpendicular to both the others, *the section* C. If the crystal have but one axis, the sections A and B pass through it, and C is at right angles to it. Then if the lamina contains both axes, its plane will be that of the section A, and the other two sections will intersect it in two lines (B and C) at right angles to each other. Conceive, now, a polarized ray to pass through such a lamina at a perpendicular incidence. Then if the plane of polarization coincide with either of the sections B and C, its polarization will be undisturbed, and the whole of the transmitted light will pass into the ordinary image. But if the plate be turned round in its own plane, the extraordinary image will reappear and become a maximum at every 45° of the plate's rotation; and if it be sufficiently thin, will exhibit some one of the colours of the rings, and the tints will descend regularly in the scale as the thickness is increased, the thickness being a measure of the tint, conformably to the general law in Art. 907, of which this is only a particular case.

938. Phenomena of crossed plates at a perpendicular incidence.

When two such plates are laid together, with their sections B and C corresponding, it is evident that they are in the same relation as if they formed part of one and the same crystal; and we might therefore expect to find what really happens, *viz.* that such a compound plate polarizes the same tint that a single plate equal to the sum of the thicknesses would do. But if they be crossed, *i. e.* laid so together that the section B of the one shall coincide with the section C of the other, M. Biot has shown that the tint polarized is that due to the difference of their thicknesses. If, therefore, this difference be exactly nothing, the crossed plates will be exactly neutralised, at least at a perpendicular incidence, and that whatever be their thickness. (To procure two plates of exactly the same thickness, we have only to choose a clear and truly parallel plate terminated by fresh surfaces of fissure, and break it across.)

939. Phenomena at oblique incidences. Fig. 192. Fig. 193.

When, however, the incidence is not perpendicular, such a compound plate as described will still exhibit colours which vary in, apparently, a very irregular manner as the incidence changes, and with different degrees of rapidity in different planes. The tourmaline apparatus here renders signal service in rendering the law of these tints, at first sight extremely puzzling, a matter of inspection. When such a crossed plate is placed between the tourmalines, crossed at right angles, it exhibits the singularly beautiful and striking phenomenon represented in fig. 192, in which the tints are those of the reflected scale of Newton, the origin being in the black cross. If the tourmalines be parallel, the complementary colours are produced with equal regularity, as in fig. 193. If the compound crystal be turned round in its own plane, the figures turn with it, but undergo no change other than an alternation of intensity, being at a maximum of brightness when the arms of the cross are parallel and perpendicular to the plane of original polarization, and vanishing altogether when they make angles of 45° with that plane. If the plates be not crossed exactly at right angles, or be not precisely of equal thickness, other phenomena arise which it is easier for the reader to produce for himself than to read a detailed account of. The same may be said of the very splendid but complicated phenomena produced by crossing two equally thick plates of biaxal crystals, such as mica, topaz, &c. having the section A at right angles to their surfaces.

940. Law of tints formed by the superposition of similar plates. Regarding, however, at present only the tint produced at a perpendicular incidence, it is found that when any number of plates of one and the same medium, of any thicknesses, are superposed with their homologous sections corresponding, the tint polarized is that due to the sum of their thicknesses; but when any one or more of them have their sections B and C at right angles to the homologous sections of the others, the tint is that due to the sum of the thicknesses of those placed one way, *minus* the sum of those of the plates placed the other way. In algebraical language, if we call t, t', t'', &c. the thicknesses, and *regard as negative* those of the plates laid crosswise, the tint T polarized by the system will be that due to the thickness $t + t' + t'' +$ &c.

941. Law of tints produced by dissimilar plates. When the ray is made to traverse a plate of quartz, zircon, carbonate of lime, or any other uniaxal crystal cut so as to contain the axis of double refraction, the same law of the tints holds good, the tint T being proportional to the thickness t of the plate, and for any given plate we have $T = k t$, k being a constant depending on the nature of the plate. Now, if several plates of different uniaxal crystals be superposed, of which t, t', &c. are the thicknesses, and if a negative value of t be supposed to denote a transverse position of the axis of the plate, the resultant tint will be represented by

$$T = k\,t + k'\,t' + k''\,t'' + \&c.$$

942. Opposite action of plates of positive and negative crystals. In this equation, if the plates be all of one substance, k, k', &c. are all alike; but if they be different, k is to be regarded as a negative quantity for all such crystals as belong to M. Biot's repulsive class, (Art. 803,) such as carbonate of lime; and positive for all such (quartz, for instance) which belong to his attractive class. Thus, each term in the above equation may change its sign from two causes, either from a change in the nature of the crystal, or from a change of 90° in its azimuth.

943. General law. The above is only a particular case of a more general law which may be thus announced,—*The tint ultimately produced is proportional to the interval of acceleration or retardation of the ordinary ray on the extraordinary, after traversing the whole system; the partial acceleration or retardation in each plate being proportional to the length of the path described within the plate, multiplied by the square of the sine of the angle which the transmitted ray makes, internally, with the optic axis of the plate, if it have but one axis, or to the product of the sines of its inclination to either, if it have two;* and this law holds good for all positions of the plates, and all arrangements of them one among the other. Thus (to instance its application) in the case of two similar and equal plates crossed at right angles; by the laws of polarization, the ray which, after its transmission through the first plate is ordinary, is refracted extraordinarily by the second, and *vice versâ;* thus the two rays, on entering the second plate exchange velocities; and, therefore, when finally emergent, since the thickness of the second is equal to that of the first, the one ray will have lost ground on the other in its second transmission just as much as it gained it in its first; and thus the interval of retardation and the tint will be reduced to nothing.

944. Superposition of plates cut at right angles to their axes. From this it appears, that if two uniaxal plates cut at right angles to the axis be superposed, and adjusted so as to have their axes precisely coincident, the system of rings will have their diameters diminished if the plates be both attractive or both repulsive; but enlarged, if their characters be opposite. The experiment is rather delicate; but if made with care, placing the plates on one another with soft wax, and adjusting their surfaces by pressure to the exact position, it succeeded perfectly in the hands of Dr. Brewster.

945. Method of ascertaining whether a crystal be positive or negative. This affords a means, independent of any measurement of the separation of the ordinary and extraordinary pencils, of ascertaining whether an uniaxal crystal be attractive or repulsive; for if its rings be *dilated* by combining it with a thin plate of carbonate of lime, cut at right angles to the axis, it is positive; if contracted, negative. A simpler and readier method still is to fasten on a plate of the substance under examination, so cut as to show the rings, a plate of sulphate of lime of moderate thickness, and then, interposing it between the tourmalines, to turn it about in its own plane. A position will be found where the rings are unaltered. In this situation the section B or C of the sulphate of lime is in the plane of primitive polarization. If the compound plate be turned 45° from this situation, it will now be observed (if the thicknesses of the two plates be properly proportioned) that the rings in two opposite quadrants are entirely obliterated; and that in the other two they are removed to a much greater distance from the centre, forming segments of larger circles, much closer together; and in which the tints, instead of commencing from the centre, commence from a black interval between two adjacent white rings in the midst of the system, and thence descend in the scale both inwards and outwards. In this state of things, the position of the sulphate of lime, with respect to the tourmalines, must be carefully noted; and the crystallized plate being detached, a plate of carbonate of lime, (perpendicular to its axis,) or of any other known uniaxal crystal, must be substituted for it; and the sulphate of lime replaced *in the same position.* If, then, it be found, that the same two quadrants of the rings are obliterated in this, as in the former case, and the new set of rings in the other quadrants be also similarly situated,—then the crystal examined is of the same character as the carbonate of lime, or other crystal used as a standard of comparison; but if, on the other hand, the quadrants where the rings were obliterated in the former case be those where the new rings are formed in the latter, then the characters of the two substances are opposite. If the crystallized plate be too thin, or of too feeble polarizing power to exhibit these phenomena with necessary distinctness, we must place it in azimuth 45° on the divided apparatus described in a former article (929;) and, fixing conveniently in the polarized beam a *very* thin plate of sulphate of lime also in azimuth 45°, ascertain, by making the crystal revolve, whether its tints have been raised or depressed in this plane by the action of the sulphate; then, removing the crystal, replace it with a standard one, and repeat the observation without touching

M. Fresnel's experiment with a bisected rhomboid.

of interference by the production of coloured fringes. To obviate this difficulty, M. Fresnel sawed in half a rhomboid of Iceland spar, the two halves of which must of necessity have, at their line of separation and its immediate confines, precisely equal thicknesses. These halves he placed one on the other, only turning one 90° round in azimuth, so as to have their principal sections at right angles. In this state, a pencil entering them nearly at the intersection of the planes of separation would at its final emergence be divided, not into four, but into two only, (see Art. 879,) the ray ordinarily refracted in the first half having undergone extraordinary refraction in the second, and *vice versâ*. The two rays, therefore, have exchanged velocities and directions, in the second transmission; and, therefore, when emergent, will have described exactly equal paths with equal velocities in each respectively, and will differ only in their states of polarization, which will be at right angles to each other. We have here, then, a case in which pencils diverge from two points side by side, and in a state in all other respects proper for interfering; nevertheless, when we look for the fringes which ought to be formed under such circumstances, (and which with natural light would be seen, see Art. 735 and 736,) none are visible. Their absence, then, must be owing to the opposite state of polarization of the interfering rays.

955. M. Arago's experiments with mica piles.

M. Arago, to make the same experiment, employed a process independent of double refraction. Two fine slits were made in a thin plate of copper, through which rays from the common origin were transmitted, and formed fringes (in their natural state) when viewed by an eye lens in the manner described, (Art. 709.) He now prepared two piles of pieces of very thin mica, or films of blown glass laid one on the other, fifteen in number, and then divided this compound plate in half by a sharp instrument, so that the halves, in the immediate neighbourhood of the line of division, could not be otherwise than of almost exactly equal thickness. These piles, when exposed at an incidence of 30° to a ray, were found to polarize the portion transmitted almost completely. They were then placed before the slits so as to receive and transmit the rays from the luminous point at precisely that incidence, and through spots which were very near each other in the undivided state of the pile. They were, moreover, so arranged, (being set on revolving frames,) that the plane of incidence could be varied (and therefore that of polarization) by turning either round in azimuth without altering its inclination to the ray, or varying the spot through which the ray passed. And it was then found, that when both piles were placed so as to polarize the rays in parallel planes, as, for instance, when both were inclined directly downwards, or one directly down and the other directly up—the fringes were formed as if the piles were away; but where one of the piles was turned round the incident ray as an axis through 90°, and so placed as to polarize the rays transmitted by it at right angles to the other, the fringes totally disappeared, nor could they be restored by inclining either pile a little more or less to the incident ray in the plane of incidence, the effect of which would be to alter gradually the length of the ray's path within the pile without changing its polarization, and thus, to compensate any slight inequality which might still subsist in their thicknesses. In intermediate positions the fringes appeared, but always the more vividly the nearer the planes of polarization approached to exact parallelism, thus attaining their maximum, and undergoing total obliteration at each quadrant of the rotation of either pile, (the other being at rest.)

956. Tourmaline plates substituted for the piles.

A plate of tourmaline carefully worked to exact parallelism, and bisected, would answer equally well with the transparent piles to polarize the rays; but the tourmaline should be selected of very homogeneous texture, such are not easy to meet with, though they may be found; and in this manner the experiment is perfectly easy and satisfactory. One half the tourmaline is fixed over one aperture, the other movable in a cell in its own plane over the other. The same phenomena will then be observed by turning round the movable tourmaline as with the oblique pile in the last experiment.

957. M. Fresnel's fundamental experiment. Analysis of the polarized tints.

An experiment still more simple, and equally conclusive, is the following, of M. Fresnel. He placed before the sheet of copper (having, as before, two narrow slits in it very near each other) a *single* thin parallel lamina of sulphate of lime. Now, as this body possesses double refraction, each pencil would be divided into two—an ordinary and an extraordinary one—which, according as they emanate from the right or left hand slit, we will term R *o*, R *e*, and L *o*, L *e*. If natural light be used to illuminate the slits, these pencils will be of equal intensity, but those marked *e* will be polarized oppositely from those marked *o*. We may then form four combinations: 1. R *o* may interfere with L *o*; 2. R *e* may interfere with L *e*; 3. R *o* with L *e*; 4. R *e* with L *o*. Now of these, R *o* and L *o* are similarly polarized, and they have described equal paths with equal velocities; therefore, supposing them capable of interference, they will give rise to a set of fringes corresponding exactly to the middle of the line joining the two slits, or, as we may express it, in the axis of the apparatus. The same may be said of R *e* and L *e*. These two sets of fringes will therefore be superposed, and appear as one of double intensity. Again, R *o* may be combined with L *e*; but as these two rays have traversed the sulphate in different directions and with different velocities, those rays of each pencil which meet *in the axis* will differ by too many undulations to produce colour; and if the pencils interfere, the place of the fringes will, instead of the axis, be shifted towards the side where the pencil has the greatest velocity, (Art. 737,) and that the more, the thicker the lamina of sulphate, so that if taken of a proper thickness, this set of fringes may be removed entirely out of the reach of the middle set, and should be seen independent of it. In like manner, the pencil R *e* may interfere with L *o*, and give rise to another set of lateral fringes; but as the ray which in the former combination was the swifter, in this is the slower, this set will lie on the opposite side of the middle set, supposing it produced at all; and thus there should be seen three sets of fringes, one bright, in the middle, and two fainter on either side. But, in fact, only one set is seen, *viz.* the middle set. Therefore the combination of the rays R *o* and L *e*, L *o* and R *e*, which are polarized oppositely, produce no fringes, *i. e.* they do not interfere.

But if we cut the lamina in half, and turn one half a quadrant round in its own plane, these rays are *then* reduced to the same polarization; and the rays R *o* and L *o*, R *e* and L *e*, which in the former case gave rise to

Experiment varied.

the central fringes, are now placed in opposite states of polarization; and it is accordingly found that the central fringes have disappeared entirely, and that two lateral sets formed respectively by R *o* and L*e*, R *e* and L *o*, have started into existence. If we turn the lamina slowly round, these will gradually fade away, and the central reappear and become brighter, and so on alternately; thus affording a convincing proof of the truth of the second of the laws above enunciated.

959. Verification of the third law.

The experiment related by Messrs. Arago and Fresnel in support of their third law is as follows: Resuming the arrangement of Art. 955 or 956, and placing the piles or tourmalines so as to polarize the two pencils oppositely, let a doubly refracting crystal be placed *between the eye and the sheet of copper*, with its principal section 45° inclined to either of the planes of polarization of the interfering rays. Each pencil will then divide itself by double refraction into two of equal intensity, and polarized in two planes at right angles, one of which is the principal section itself. We ought, therefore, to expect to see two systems of fringes, one produced by the interference of the ordinary ray from the right hand aperture (R *o*) with that of the left (L *o*,) and the other by that of R *e* with L*e*; yet no fringes are seen. The experiment may be varied by substituting for the doubly refracting prism a tourmaline, or pile, with its principal section in azimuth 45°. This must reduce to a common polarization all the rays which traverse it, *viz.* the half of each pencil, yet no fringes are seen, and therefore no interference takes place.

960. Experiments in proof of the fourth and fifth laws.

The following experiment is adduced in the Memoir cited in support of the fourth and fifth of the above laws. A lamina of sulphate of lime is perpendicularly exposed to a polarized pencil diverging from a minute point, and immediately behind it is placed a plate of brass pierced with two very small holes near together. The principal section of the lamina is to be placed at an angle of 45° with the plane of primitive polarization. In consequence, from each of the holes (right, R,—and left, L) will emerge a ray composed of two equal rays, R *o* and R *e*, and L *o*, L *e* oppositely polarized, *viz.* at angles + 45° and − 45° with the plane of primitive polarization, which we will suppose vertical. In this situation of things a rhomboid of Iceland spar is placed between the two holes, and the focus of the eye lens employed to view the fringes, with its principal section vertical, *i. e.* making again with that of the lamina angles of 45° either way. Each of the four rays then above mentioned will be divided into two equal rays, an ordinary and an extraordinary, thus giving rise in all to the eight rays

R *o o*, R *e o*; L *o o*, L *e o*; R *o e*, R *e e*; L *o e*, L *e e*.

These rays are received on the eye lens, and conveyed into the eye. Let us now examine their respective route and states of polarization.

961. First, then, the rays R *o* and R *e*, after quitting the lamina, are parallel; and by reason of the very small thickness of it, may be regarded as superposed, being undistinguishable from each other; but they have described within the lamina different paths by different velocities, so that on emerging they will differ in phase, by an interval of retardation proportioned to the thickness of the lamina, and which we will call d, so that x being the phase of the ray R *o*, $x + d$ will be that of R *e*. The very same may be said of L *o* and L *e*. Moreover, the two rays of either of these pairs respectively are oppositely polarized, *viz.* in planes + 45° and − 45° from the vertical. This we may represent at once thus:

Ray.	Phase.	Plane of Polarization.
R *o*	x	+ 45°
R *e*	$x + d$	− 45°
L *o*	x	+ 45°
L *e*	$x + d$	− 45°

962. Next, the portions into which either of these rays is subdivided, in traversing the rhomboid, follow in their passage through it different paths, and have different velocities; but all which are refracted *ordinarily* have one common direction and velocity; and so of those refracted extraordinarily; hence, between the ordinary and extraordinary rays here produced, will arise a difference of phase which we shall call δ, so that if x be the phase of any ordinary ray, $x + \delta$ will be that of the corresponding extraordinary one; and their planes of polarization will be opposed, and will form angles respectively = 0 and 90° with the vertical. Thus the circumstances will stand thus:

	A.			B.	
Ray.	Phase.	Plane of Polarization.	Ray.	Phase.	Plane of Polarization.
R *o o*	x	0°	R *o e*	$x + \delta$	90°
R *e o*	$x + d$	0°	R *e e*	$x + d + \delta$	90°
L *o o*	x	0°	L *o e*	$x + \delta$	90°
L *e o*	$x + d$	0°	L *e e*	$x + d + \delta$	90°

963. These eight pencils are all equal in intensity, and all those contained in the first set (marked A) will meet in one part of the field of view, while those marked B (on account of the thickness of the rhomboid, which we here suppose considerable, so as to produce a sensible, and even a large separation of the ordinary and extraordinary pencils) will meet in another, distant from the point of concourse of (A) by an interval proportional to the thickness of the rhomboid, and which we will here suppose so large as to throw the fringes (if any) there produced, entirely out of the way of mixing with those produced at the concourse of A. Let us then consider separately, the pencils of rays of the parcel A, and see what interferences can take place. And first, R *o o* may

combine with L *o o*, and since their difference of phase is zero, they will interfere in the axis of the apparatus; and their planes of polarization being coincident, there is no reason why fringes should not there be produced by their concourse. The same holds good of the combination R *e o* and L *e o*, and, consequently, there will be superposed on each other in the axis two sets of fringes, producing one of double brilliancy.

964. Next, R *o o* may interfere with L *e o;* but there being a constant difference of phases *d* in favour of the latter, the fringes produced by their concourse will lie to the left of the axis, by an interval proportional to the thickness of the lamina of sulphate, and will be seen separately. Similarly, the concourse of the pencils R *e o* and L *o o* will determine the production of another set of lateral fringes; but the difference of phases *d* being in this case in favour of the right hand pencil, this system will be situated as much to the right of the axis as the other was to the left.

965. Thus in the ordinary image three sets of fringes ought to be seen, and in the extraordinary, by a similar reasoning, as many. Now, in fact, this is the case, and the phenomena are seen on making the experiment precisely as here described. But it is evident that the rays which form the lateral fringes, by their interferences, are precisely those which, at their leaving the sulphate, had opposite polarizations, but have been afterwards reduced to similar polarization by the action of the rhomboid.

966. Variation of the experiment.

Allowance of half an undulation.

If instead of a rhomboid of sensible double refraction we substitute a plate of sulphate of lime, or of rock crystal, so thin as to produce no visible separation of the pencils, the fringes produced by the pencils B will be superposed on those arising from the interference of the pencils A, and we should expect therefore, instead of six, to see three sets of fringes, the middle one being still the brightest. But, in fact, we see but one set, and the lateral fringes vanish altogether. This remarkable result proves that the colours resulting from the concourse of the rays ordinarily refracted by the rhomboid, are complementary to those resulting from that of the extraordinary rays; and therefore that we must allow half an undulation to be gained or lost when we would pass from one set to the other, precisely as in the phenomena of the reflected and transmitted colours of thin plates.

967. Application to the colours of crystallized laminæ.

One of the most important consequences of these laws, is that they supply the defective link in the chain which connects the doctrine of undulations with the colours of crystallized laminæ as described in the last section. It had been already remarked (as we have seen) by Dr. Young, that the passage of the ordinary and extraordinary rays with different velocities through the crystallized plate, would give rise to that difference of physical condition of the rays at their emergence which would lead to the production of colours; but the difficulty remained to explain, not why colours were produced in certain circumstances, but why they were not produced in all, in short, what share the polarization of the incident, and the analysis of the emergent rays, had in the production of the phenomena.

968. Why colours are not seen through a thin crystallized plate alone.

To see the nature of this difficulty more clearly, imagine a wave proceeding from a distant radiant point to be incident on a very thin crystallized lamina. It will be subdivided into two, each traversing the plate in a different direction and with its own proper velocity, and each of them emerging parallel to its original direction. The incident wave will, after emergence be resolved into two parallel to each other, but separated by a small interval equal to the interval of retardation. Now the hindmost of these ought, according to the law of interferences, to interfere with a subsequent wave of the system to which the foremost belongs, and thus periodical colours should arise on merely looking against the sky through such a lamina without any other apparatus. Why then are none seen? To this the law of Messrs. Arago and Fresnel afford a satisfactory answer. The two systems of waves into which the incident system is resolved are *oppositely polarized*, and therefore, though all other conditions be satisfied, incapable of interfering.

969. Fig. 194. Explanation of the colours of the polarized rings.

To understand how the colours of the polarized rings must be conceived to be produced by interference, let us take the simplest case when a polarized ray, A B, fig. 194, is incident on any thin crystallized plate B, whose principal section is 45° inclined to the plane of primitive polarization. Let A be the system of waves which constitutes the incident ray; then in its passage through the crystallized lamina it will be divided into systems O and E of equal intensities, polarized in planes $+ 45°$ and $- 45°$ inclined to that of primitive polarization, and the one lagging a few undulations behind the other, so as to interfere, as represented in the figure, and constituting the parallel rays C F and D G. Let these now be received on, and transmitted through, a doubly refracting prism F G H L placed with its principal section in the plane of primitive polarization, or 45° inclined to that of the crystallized lamina. Then will each of the incident rays be again subdivided, C F into H M and I P, and D G into K N and L Q, all of equal intensity. Of these, H M and K N emerge parallel, as also K N and L Q respectively. Now the systems of waves O and E which follow each other at a certain interval *d* will continue to do so in both the refracted rays, as if they formed one compound system; so that each of the pencils H M K N and I P L Q will consist of a double system of waves O *e* and E *e*, O *o* and E *o* respectively. The former pair following each other at the interval *d*, and the latter at the interval $d \pm \frac{1}{2}$ undulation, (by reason of the demonstrated fact, that in passing from the ordinary to the extraordinary system half an undulation must be allowed. See Art. 966.) Now as each ray of these pairs respectively have similar polarizations, *viz.* those of the pair ordinarily refracted (O *o* and E *o*) in the plane of the principal section of the prism, and those of the extraordinary pair O *e* and E *e* in a plane at right angles to it, there is no reason why interference should not take place, and the consequence must be, the production of complementary colours in the two pencils finally emergent corresponding to the intervals of retardation d and $d + \frac{\lambda}{2}$, which is just what really happens.

970. Explanation of the complementary tints.

Conceive now another ray incident on B in the direction A B, but polarized in a plane at right angles to that of the ray considered in the last paragraph. Then this will undergo precisely the same series of divisions and subdivisions as the former. But the intervals of retardation will be different; for its plane of polarization when incident on B being *now* related to the plane of ordinary refraction, as that of the other ray at its incidence was to the extraordinary, and *vice versâ*, a difference of half an undulation must (as already explained) be admitted in the relative position of the two systems of waves O, E, at their emergence, from this cause, independent of the interval of retardation within the plate; so that if d were the interval in the former case, $d - \frac{1}{2}\lambda$ will be the difference now, and, after passing through the prism, we shall have for the intervals of retardation in the two binary pencils, instead of d and $d + \frac{1}{2}\lambda$ which they were before, $d - \frac{1}{2}\lambda$ and d. Hence the two pencils will exchange colours when the polarization of the incident light is varied by a quadrant, and this is also conformable to fact. If this reasoning be not thought conclusive, the reader is referred forwards to Art. 983 and 984.

971. Why colours are not produced by unpolarized light.

Next, let the incident ray be unpolarized. This case, as we have seen Art. 851, is the same with that of a ray consisting of two equal rays oppositely polarized, and therefore in each pencil will coexist, superposed on each other, the primary and complementary colour arising from either portion, which being of equal intensity will neutralize each other's colours and the emergent pencils will be white, and each of half the intensity of the incident beams. This then is the reason (on this doctrine) why we see no colours when the light originally incident on the crystallized plate is unpolarized.

972. M. Fresnel's general rule for determining how to allow for the half undulation gained or lost.

Fig. 195.

Thus, the theory of interferences, modified by the principles above stated, affords, as we see, an explanation of the colours of crystallized plates totally distinct from that of movable polarization. The only delicacy in its application to all cases, lies in the determination which of the emergent pencils must be regarded as having its interval of retardation increased by half an undulation. M. Fresnel gives the following rule for this essential point. (Note on M. Arago's Report to the Institute on a Memoir of M. Fresnel relative to the colours of doubly refracting laminæ, *Annales de Chimie*, vol. xvii. p. 80.*) *The image whose tint corresponds precisely to the difference of routes, is that in which the planes of polarization of its constituent pencils after having been separated from each other, are brought together by a contrary motion, while, on the other hand, the pencils whose planes of polarization are brought to coincidence by a continuance of the same motion by which they were separated, produce by their reunion the complementary image.* To understand this better, let P C be the plane of primitive polarization projected on that of the paper, to which let us suppose the ray perpendicular, C O that of the principal section of the crystallized lamina, and C S that of the principal section of the doubly refracting prism; then the incident pencil polarized in the plane P P′ will after penetrating the lamina be divided into two, one O polarized in the plane C O, the other E in the plane C E perpendicular to it. Now, C O may always be so taken as to make an angle not greater than a right angle with C P, and C E so as to have C P *between* C E and C O; so that the plane C P may be conceived to open or unfold itself like the covers of a book, into C O and C E, one on either side. Again, C S may always be regarded as making an angle not greater than a right angle with C O, and when the ray O resolves itself into two (O *o* and O *e*) by refraction at the prism, its plane of polarization C O may be conceived to open out into the two C S and C T at right angles to each other, including C O between them; and in like manner the ray E will resolve itself into two E *o* and E *e*, and its plane of polarization C E will open out into the two C S and C T′, having C E between them in the case of fig. 195 (*a*), and into C S′ and C E in that of fig. 195 (*b*); in the former case C T′ is a prolongation of C T, in the latter C S′ is a prolongation of C S. The rays O *o* and E *o* then which make up the ordinary pencil, have, in the case of fig. (*a*), been each brought to a coincident plane of polarization C S by two motions in contrary directions, as represented by the arrows, and the extraordinary ones O *e* and E *e* have been separated and brought back to a coincident plane by motions continued in the same direction for each respectively. The reverse is the case in fig. *b*. In the case then of fig. *a* the colours of the ordinary pencil O *o* + E *o* will be those which correspond precisely to the difference of routes, and those of the extraordinary one O *e* + E *e* will correspond to that difference *plus* half an undulation, while in that of fig. *b* the reverse happens. This rule is empirical, *i. e.* is merely a result of observation. It is clear that the principle of the conservation of the *vis viva* in this, as in the colours of uncrystallized plates, requires that the two images should be complementary to each other, and therefore half an undulation *must* be gained or lost by one or the other pencil, but which of the two is to be so modified we have no means of knowing *a priori.*

973. This once determined, however, we have no difficulty in deducing the formulæ of intensity and other circumstances of the phenomena when the azimuth of the crystallized plate is arbitrary, instead of being, as we have hitherto supposed, limited to 45°. The analytical expressions of the intensity of the pencils we must reserve for our next section.

§ IX. *Of the application of the Undulatory Doctrine to the explanation of the phenomena of Polarized Light and of Double Refraction.*

974. Newton's objections against the undulatory theory.

The phenomena of double refraction and polarization, as exhibited in the experiments of Huygens on Iceland spar, were regarded by Newton and his followers as insuperable objections to the undulatory doctrine, inasmuch as it appeared to them impossible, by reason of the *quaquâversum* pressure of an elastic fluid, to conceive an undulation as having a different relation to different regions of space, or as possessing *sides*. "Are not," says Newton, "all hypotheses erroneous in which light is supposed to consist in pressure or motion propagated through a fluid medium?"........ "for pressures or motions propagated from a shining body through an uniform medium, must be on all sides alike, whereas it appears that the rays of light have different properties in their different sides."........ "To me, this seems inexplicable, if light be nothing else than pressure or motion propagated through ether." *Opticks*, book iii. quest. 28. And, again, quest. 29; "Are not rays of light very small bodies emitted from shining substances?"........ "The unusual refraction of Iceland crystal looks very much as if it were performed by some kind of attractive virtue lodged in certain sides both of the rays and of the particles of the crystal."...... "I do not say this virtue is magnetical.—It seems to be of another kind. I only say, that, whatever it be, it is difficult to conceive how the rays of light, unless they be bodies, can have a permanent virtue in two of their sides which is not in their other sides, and this, without any regard to their position as to the space or medium through which they pass."

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* This Memoir was read to the Institute, Oct. 7, 1816. A Supplement was received Jan. 19, 1818. M. Arago's report on it was read June 4, 1821. And while every optical philosopher in Europe has been impatiently expecting its appearance for seven years, it lies as yet unpublished, and is known to us only by meagre notices in a periodical Journal.

975. Examined. Although we have no knowledge of the intimate constitution of elastic media, or the manner in which their contiguous particles are related to each other and affect each other's motion, yet it is certain that the mode and laws of the propagation of motion through them by undulation cannot but depend very materially on this connection. The only analogies we have to guide us into any inquiry into these laws, are those of the propagation of sound in air or water, and of tremors through elastic solids, and along tended chords and surfaces; and such is the extreme difficulty of the subject when taken up in a purely mathematical point of view, that we are forced to have recourse to these analogies, and, dismissing in the present state of science the vain hope of embracing the whole subject in analytical formulæ, suffer ourselves to be instructed by experience, as to what modifications the peculiar constitution of vibrating media may produce in the propagation of motion through them. Now, when sound is propagated through air or water, in which the molecules are at least *supposed* to have no mutual connection but to be capable of moving with equal facility, and to be restored to their places with equal elastic forces, in whatever direction they are displaced, and in which, moreover, it is (at least theoretically) taken for granted, that the motion of any molecule has an equal tendency to set in motion those adjacent to it, in whatever direction these may be situated with respect to it; it is difficult to conceive that the motion of a molecule in the surface of a wave, at some distance from the centre whence the sound emanates, can be performed otherwise than in the direction of the radius, or at right angles to the surface of the wave; so that in this case the motion of the vibrating molecules must coincide with the direction of the rays of sound, and there appears, therefore, no reason why such rays should bear different relations to the different regions of space surrounding them, whether right or left, above or below; for the ray being regarded as an axis, all parts of the sphere round it are similarly related to it.

976. But if we conceive a connection of any kind, such as may possibly be established by repulsive and attractive forces, or magnetic or other polarities subsisting between the molecules of the vibrating medium, the case is altered. It will no longer then follow of necessity, that the individual motion of each molecule is performed in the direction in which the general wave advances, but it may be conceived to form any angle with that direction, even a right angle. A familiar instance of such a mode of propagation may be seen in the wave which runs along a long stretched cord, struck, shaken, or otherwise disturbed at one end. The direction of the wave is the length of the cord, and that of the motion of each molecule lies in a plane perpendicular to it. Now this is precisely the kind of propagation which M. Fresnel conceives to obtain in the case of light. He supposes the eye to be affected only by such vibrating motions of the ethereal molecules as are performed in planes perpendicular to the directions of the rays. According to this doctrine, a polarized ray is one in which the vibration is constantly performed in one plane, owing either to a regular motion originally impressed on the luminous molecule, or to some subsequent cause acting on the waves themselves, which disposes the planes of vibration of their molecules all one way. An unpolarized ray may be regarded as one in which the plane of vibration is perpetually varying, or in which the vibrating molecules of the luminary are perpetually shifting their planes of motion, and in which no cause has subsequently acted to bring the vibrations thus excited in the ether to coincident planes.

Fresnel's theory of transverse vibrations.

977. Propagation of light assimilated to that of waves along a stretched cord. The analogy of the tended cord (which appears to have suggested itself to Dr. Young on considering the optical properties of biaxal crystals in 1818) will help our conception greatly. Suppose such a cord of indefinite length, stretched horizontally, and one end of it being held in the hand, let it be agitated to and fro with a motion perpendicular to the length of the cord. Then will a wave or succession of waves be propagated along it, and every molecule of the cord will, after the lapse of a time proportional to its distance from the hand, begin to describe a line or curve similar and similarly situated to that described by the extremity at which the agitation originates. If the original agitation be regularly repeated and constantly confined to one plane, the same will be true of the motion of each molecule, and the whole extent of the cord will be thrown into the form of an undulating curve lying in one plane, so far as the motion has reached. In this case it will represent a polarized ray or system of waves. If, after a few vibrations in one plane, the extremity be made to execute a few in another, and then again in another, and so on, so that the plane of vibration shall assume in rapid succession all possible situations, since each molecule obeys exactly the same law of motion with the extremity, the curve will consist of portions lying in all possible planes, and since by reason of the propagation of the undulation along it, every point of it is in succession agitated by the motion of every other, all these varied vibrations will run through any given point of it, and were a sentient organ like the human retina stationed there, the impression it would receive would be analogous to that excited in the eye by an unpolarized ray of light.

978. Objections considered. It may be objected to this mode of conceiving the luminiferous undulations, that the molecules of the ether, if it be a fluid, such as we have hitherto all along regarded it, cannot be supposed connected in strings, or chains like those of a tended cord, but must exist separate and independent of each other. But it is sufficient for our purpose to admit such a degree of lateral adhesion (we hesitate to term it *viscosity*) as may enable each molecule in its motion not merely to *push before it* those which lie directly in the line of its motion, but to *drag along*

with it those which lie on either side, in the same direction with itself. Or, acknowledging at once the difficulty, since light is a real phenomenon, we are not to expect it to be produced without a mechanism adequate to so wonderful an effect. We do not hesitate to attribute to the fluids which are imagined to account for the phenomena of heat, electricity, magnetism, &c. properties altogether repugnant to our ordinary notions of fluids, and why should we deny ourselves the same latitude when light is to be accounted for. It is true the properties we must attribute to the ether appear characteristic of a solid than of a fluid, and may be regarded as reviving the antiquated doctrine of a plenum. But if the phenomena can be thereby accounted for, *i. e.* reduced to uniform and general principles, we see no reason why that, or any still wilder doctrine, should not be admitted, not indeed to all the privileges of a demonstrated fact, but to those of its representative, or *locum tenens*, till the real truth shall be discovered. Assuming it, then, with M. Fresnel, as a postulatum, that the vibrations of the ethereal molecules which constitute light are performed in planes at right angles to the direction of the ray's progress, let us see what account can be given of the phenomena of polarized light.

979. Explanation of the phenomena of interference on this doctrine.

And first, then, of the interference of two polarized rays, whether polarized in the same, or different planes. The plane of polarization in this doctrine may be assumed to be either that in which the vibrations are executed, (*i. e.* a plane passing through the direction of the ray and the line described by each of the vibrating molecules in its excursion,) or one perpendicular to it, which we please. Reasons, presently to be stated, render the latter preferable, but at present it is a matter of indifference which we assume. Now, in § 3, Part III. we have investigated at length, with a view to the present inquiry, the modes of vibration which result from the combination of any assigned vibrations, whether executed in the same or different planes; and it follows from the purely mechanical principles there laid down, 1st, That the combination of two vibrations executed in the same plane, produces a resultant vibration in the same plane, which may be of any degree of intensity from the sum to the difference of the intensities of its component vibrations, according to the difference of their phases. Now, each of these systems of vibration represents a polarized ray; so that rays polarized in the same plane ought, on these principles, to be capable of destroying or reinforcing each other by interference, as we see they do. But the case is otherwise when the component vibrations are executed in different planes, for in that case it is obvious that they never can destroy each other completely so as to produce rest. The general case of non-coincident planes of vibration is analyzed in Art. 618; and in Art. 621 we see, that even when each of the component vibrations is rectilinear, the resultant is elliptic; so that each molecule of the ether performs continual gyrations in one direction, and never can be totally quiescent.

980. Analogy of the stretched cord.

Thus we see that the interference of rays similarly polarized, and the non-interference of those dissimilarly, is a necessary consequence of the hypothesis we are considering; and indeed was the phenomenon which first suggested it. It may be familiarly explained by the analogy of our tended cord. Conceive such a cord to have its extremity agitated at equal regular intervals with a vibratory motion performed in one plane, then it will be thrown, as we have seen, into an undulatory curve, all lying in the same plane. Now, if we superadd to this motion another, similar and equal, but commencing exactly half an undulation later, it is evident that the direct motion every molecule would assume, in consequence of the first system, will at every instant be exactly neutralized by the retrograde motion it would take in virtue of the other; and, therefore, each molecule will remain at rest, and the cord itself be quiescent. But if the second system of motions be performed in a plane at right angles to the first, the effect will evidently only be to distort the figure of the cord into a curve of double curvature, which, in the general case, will be an elliptic helix, and will pass into the ordinary circular one when the two component vibrations differ in phase by a quarter of an undulation, or 90°. (See Art. 627. *Corol.*)

981. Case of a rotatory or spiral motion.

In this case the extremity of the cord describes a circle with a continuous motion, and this motion is imitated by each molecule along its whole length. It is easy to make this a matter of experiment; we have only to hold in our hands the end of a long stretched cord, or grasp it firmly in any part of its extent, and work the part held round and round, with a regular circular motion, and we shall see the cord thrown into a helicoidal curve, each portion of which circulates in imitation of the original source of the motion

982 Resultant of two rays oppositely polarized investigated

But experience shows, not merely that two equal rays polarized at right angles do not destroy each other for any assignable difference of origins, but, that whatever be this difference, the intensity of the resultant ray remains absolutely the same. Now this is also a necessary consequence of the theory of transverse vibrations. To show this, we need only refer to the expressions for A, B, C in equation (7,) Art. 619, resuming at the same time the notation and reasoning of that article. The intensity of the impression made on the eye by any ray being proportional to the *vis viva*, is represented by the sum of the several *vires vivæ* in the three rectangular directions, or by $A^2 + B^2 + C^2$, that is, by

$$a^2 + b^2 + c^2 + a'^2 + b'^2 + c'^2 + 2\,a\,a' . \cos(p - p') + 2\,b\,b' . \cos(q - q') + 2\,c\,c' . \cos(r - r').$$

Now if we assume the directions of the coordinates x and y to be those transverse to that of the ray, and the one in the plane of polarization of one ray, the other in that of the other, at right angles to it, and that of z in the direction of the ray itself, we have

$$a' = 0, \quad b = 0 \quad c = 0, \quad c' = 0;$$

and therefore the above expression for the intensity becomes

$$A^2 \quad B^2 + C^2 = a^2 + b'^2,$$

which is independent of $p - p'$, $q - q'$, $r - r'$, the difference of phases, and is equal to the sum of the intensities of the separate rays. And we may remark, by the way, that no other supposable mode of vibration but that in question, in which c and c′, the amplitudes of vibration in the direction of the ray vanish, could produce the same result. (Fresnel's *Considerations Théoriques sur la Polarization de la Lumière. Bulletin de la Société Philomatique*, October, 1824.)

983. Rationale of the rule for allowing half an undulation. Fig. 195.

Let us now consider what will happen when a ray polarized in any plane is resolved into two polarized in any other two planes at right angles to each other, and these again reduced to two others also at right angles to each other, by a second resolution. Suppose C, (fig. 195, *a*) to be the course of a ray projected on a plane perpendicular to its direction, (that of the paper,) and in which, consequently, the vibrations of the molecule C are performed. Let P C P′ be the line of vibration of this molecule, and therefore (according to the hypothesis assumed) at right angles to the plane of primitive polarization. When this ray is divided into two others oppositely polarized, the vibrations are of course resolved into two others performed in planes at right angles to each other. Let C O and C E be the projections of these planes, which are therefore perpendicular to the planes of polarization of the two new rays respectively. Suppose that at any instant the molecule C of the primitive ray is moving *from* C in the direction C P; then this motion, if resolved into two, will give rise to two motions, one in the direction *from* C *towards* O, the other *from* C *towards* E. If each of these motions be again resolved into two, in planes whose projections are S C S′ and T C T′, at right angles to each other, that in the direction C O will produce two motions, one in the direction C S, and the other in the direction C T; and on the other hand the motion in the direction C E will produce one in the direction C S, and the other (in the case of fig. 195, *a*) in the direction C T′ opposite to C T. Thus the two resolved motions in the plane S S′ will conspire, but those in the plane T T′ will oppose, each other. In the case of fig. 195, *b*, the reverse will happen; the motions in the plane T, T′ conspiring, and those in the plane S S′ opposing, each other. For simplicity of conception, however, we will confine ourselves to the former case. If, now, we pass from the consideration of the vibrations to that of the rays, it will appear that we have, in fact, resolved the original ray polarized in the plane P P′ into two, polarized in planes perpendicular respectively to C O and C E; and these again, finally, each into two, *viz.* one polarized in the perpendicular to S S′, and one perpendicular to T T′. The two portions polarized perpendicular to S S′ form one ray, and those perpendicular to T T′ another; but in the former, the component portions tend to strengthen,—in the latter, to destroy each other. Hence, if we consider the two former portions as having a common origin, we must regard the latter as differing by half an undulation.

984. Hitherto we have supposed the second resolution of the rays to take place at the same point C in the course of the ray as the first, but this may not be the case, and several cases may be imagined; first, we may suppose the two portions into which the ray is first resolved to run on in the same line with equal velocities; and after describing any given space, to be then resolved, at another point C′ (whose projection in the figure will coincide with C) into the final rays S S′ and T T′. It is evident that this will make no difference in the result, for the phases in which each ray arrives at C′ will be alike; and after the second resolution the conspiring vibrations in the direction S S′ will still be in the same phase, and the opposing ones in the plane T T′ must still be regarded as in opposite phases, *i. e.* as differing by half an undulation. Or, secondly, we may suppose, that, owing to any cause, the two resolved rays do not travel with equal velocity, (as in the case where the resolution is performed by double refraction.) In this case, if i be the interval of retardation of the one ray on the other when they arrive at C′, i will represent the difference of phases of the two rays at the instant of their second resolution. Consequently, when resolved, the final ray, whose vibrations are performed in S S′, will be the *sum*; and that whose vibrations are performed in T T′, the *difference* of two rays, one in a certain phase (θ), the other in the phase $\theta + i$; or, which is the same thing, the former will be the *sum* of two components in the phases θ and $\theta + i$; the latter, the *sum* of two in the phases θ and $\theta + i + 180°$, so that still the difference of half an undulation is to be applied. In the case of fig. 195, *b*, if we pursue the same reasoning, it will appear that this difference still subsists, but must be applied conversely, *viz.* to the compound ray whose vibrations are performed in C S.

985. We have here, then, the theoretical origin of the allowance of half an undulation, in those cases where it is required to account for the polarized tints, Art. 966, and of the rule laid down in Art. 972 for its correct application. However arbitrary the assumption may have appeared as there presented, and however singular it may have seemed to make the affections of a ray at one point of its course dependent on those which it had at a former instant, we now see that the whole is a direct and very simple consequence of the ordinary elementary rules for the composition and resolution of motions. It is worthy of notice, that the fact was ascertained *before* the theory of transverse vibrations was devised, so that this theory has the merit of affording an *a priori* explanation of what had previously all the appearance of a mere gratuitous hypothesis.

986. Application of the analogy of the stretched cord. Fig. 196.

In conceiving the resolution of a ray into two others polarized in different planes, we may be aided by the analogy of the tended cord, which we have before had occasion to refer to. In fig. 196 let A B be a stretched cord, branching at B into the two B C and B D, making a small angle with each other at B, and having either equal or unequal tensions. Suppose the plane in which the two branches lie to be (for illustration's sake) horizontal, and let the extremity A of the single cord be made to vibrate regularly in a vertical plane; or, at least let the vibrations of the cord, before arriving at B, be reduced to a vertical plane by means of a small polished vertical guide I K, against which the cord shall press lightly, and on which it may slide freely without friction. Beyond the point of bifurcation B, and at such a distance that the excursions of the molecule B shall subtend no sensible angle from them, let two other such polished *guiding planes* be placed, inclined at different angles to the horizon, and making a right angle with each other. Suppose now B to make any excursion from its point of rest, then were the plane E F parallel to I K, the molecule of the branch B C contiguous to E F would slide on E F through a space equal to the whole excursion of B; but since it is inclined to I K at an angle

($= \theta$) a part only of the motion of B will be employed in causing this molecule to glide on E F, and the remainder will cause the cord to bend over and press on the obstacle; but by reason of the minuteness of the excursions of B, this bending and the resistance of the obstacle and consequent loss of force will be very minute and may be neglected. Now, since the pressure of the obstacle removes the cord from the position it would have taken had no obstacle existed, in a direction perpendicular to its surface, it is easy to see that the amplitude of excursion of the contiguous molecule *on the plane* E F must be to that of B as $\cos \theta$ to radius; and, therefore, calling a the amplitude of B's excursions, $a \, . \cos \theta$ will be that of the molecule contiguous to E F, and of course that of every subsequent molecule of the branch B C. Here the part of B's motion, which is perpendicular to E F, is not expended or destroyed in bending the cord B C over the obstacle, but remains in activity, and exerts itself on the branch B D, causing it to glide on the plane G H; and the amplitude of the excursions of the molecule in contact with this plane will in like manner be represented by $a \, . \cos$ (inclination of G H to I K,) that is, by $a \, . \cos (90 - \theta)$, or by $a \, . \sin \theta$. The *vis viva*, then, in each of these respective planes is represented by $a^2 \, . \cos \theta^2$ and $a^2 \, . \sin \theta^2$, whose sum is equal to a^2, the initial *vis viva*.

987. Rationale of Malus's rule for the intensity of the complementary rays.

If we decompose, in like manner, the maximum velocity a of the ethereal molecule C (fig. 195) in the direction C P into two in the respective directions C O and C E, we get $a \, . \cos \theta$ and $a \, . \sin \theta$ for the elementary velocities; and since the amplitudes, *cæteris paribus*, are as the velocities, (Art. 610,) the amplitudes of the component rays will be respectively $a \, . \cos \theta$ and $a \, . \sin \theta$; and their intensities, which are as the squares of the amplitudes, (Art. 605,) will be $a^2 \, . \cos \theta^2$ and $a^2 \, . \sin \theta^2$. Now this is the very law propounded by Malus for the intensities of the two portions into which a polarized ray is divided by double refraction, and of which the theory of transverse vibrations gives, as we see, a simple and rational *à priori* account, thus raising it from a mere empirical law to the rank of a legitimate theoretical deduction.

988. Case of the two resolved undulations propagated with different velocities.

We have not done with the analogy of the tended cord. What we have shown in Art. 986 is independent of the tensions of the branches into which the cord is divided, and relates only to the amplitudes of their excursions from rest when thrown into vibration. But the velocity with which the waves, once produced, will be propagated along either branch depends solely on its tension. Nothing, however, prevents the tensions of the two branches from being very different; for, whatever be the ratio of two forces applied in the directions B C and B D, they may be balanced at B by a proper force applied along any other line as B A. Hence the waves will run along B C and B D with different velocities. Similarly, if we conceive, that owing to the peculiar constitution of crystallized bodies, and the relation of their particles to the ether which pervades them, its molecules are more easily displaced, or yield to a less force in certain planes than in others; or, in other words, that it possesses different elasticities in different directions; then will the planes of polarization assumed by the resolved portions of the rays determine the elasticities brought into action, and, by consequence, the velocities of their propagation. Now we have, in a former section, shown that the bending of a ray at the confines of a medium depends essentially on its velocity within as compared with that without, by the analytical relations deduced from the "principle of swiftest propagation." A difference of velocity, therefore, draws with it, as a necessary consequence, a diversity of path; and thus the bifurcation, or double refraction of a ray incident on a crystallized surface, presents no longer any difficulty in theory, provided we can find an adequate reason for the resolution of its vibrations into two determinate planes at the moment of its entering the crystal.

989. Explanation of the phenomena of double refraction in crystals with one axis.

Let us take (with M. Fresnel, *Annales de Chimie*, xvii. p. 179 *et seq.*) the case of a crystal with one axis. We may regard this, or rather the ether within it, modified in its action by the molecular forces of the crystal, as an elastic medium in which the elasticity in a direction perpendicular to the axis is different from that in a direction parallel to it, that is, in which the molecules are more easily compressible in the one than in the other direction; but, equally so in all directions perpendicularly to the axis, on whatever side the pressure be applied. To aid our conceptions in imagining such a property, we may assimilate an uniformly elastic medium to an assemblage of thin, elastic, hollow, spherical shells in contact; and such a medium as we are considering, to a similar assemblage of oblate or prolate hollow ellipsoids, arranged with all their axes parallel to one common direction, which is that of the axis of the crystal.* It is evident that the resistance of the spherical assemblage to pressure must be the same in all directions, but that of the spheroidal must differ according as the pressure is applied perpendicularly or parallel to the axis. Thus, it is easy to crush an egg by a force applied in the direction of its shorter diameter, which will yet sustain a violent pressure applied at the extremities of its longer. It is, moreover, evident, if any molecule of such an assemblage were disturbed, so as to throw it into vibration, that, provided always the amplitude of its excursions were extremely small compared to the diameter of each ellipsoid, the immediate tendency of the vibration will be to communicate motion to two strata only of molecules, *viz.* that in which the axis and equator of the disturbed molecule lie respectively, since it is only at the poles and equator that they touch, and therefore only through these points that motion can be communicated from one to the other. Consequently, any motion communicated to a molecule of such a mass could only be propagated by vibrations performed in planes parallel and perpendicular to the axis. Hence, if a vibratory motion in any plane be propagated into such an assemblage of particles from without, it will immediately, on its reaching it, be resolved into two, in the planes above named; and these, by reason of the different elasticities, will be propagated with different velocities.

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* The idea of spheroidal *molecules* in Iceland spar suggested itself to Huygens (rather fancifully, perhaps) as a means by which spheroidal *undulations* might be propagated through it, (*Op. Reliq.* tom. i. *Tractatus de Lumine*, p. 70, cited by Wollaston, *Phil. Trans.* ciii. p. 58;) and the last-named eminent Philosopher, in the Bakerian Lecture for 1813, has most ingeniously shown how such molecules may be combined to build up crystals, having the primitive forms and cleavages of acute and obtuse rhomboids. It is true, that in all this there is much hypothesis; and it should be observed, too, that the crystallographic structure would require *oblate* spheroids, where in the text we have employed *prelate*, and *vice versâ*. But we intend there only an *analogy*, not a *theory*. It would be easy to devise hypothetical modes of action where these forms might be reversed if needful.

990. Bifurcation of the refracted ray explained.

The reader must not suppose that this is intended for an account of the real mechanism of crystallized bodies. It is merely intended to show that it is not absurd, or contradictory to sound mechanical principles, to assume that such *may* be their constitution, that vibrations can only be propagated through them by molecular excursions executed in planes parallel and perpendicular to their axes. Assuming, then, that such is the case, the vibrations of a ray incident on such a crystal will be resolved into two, performed in these respective planes, and their velocities of propagation being different, the rays so arising will follow different courses when bent by refraction. Let us first consider that whose vibrations are executed in planes perpendicular to the axis. Since the crystal is symmetrical with respect to its axis, and equally elastic in all directions perpendicular to it, the velocity of propagation of this portion will be the same in all directions. Its index of refraction, therefore, will be constant, and the refraction of this portion will follow the ordinary law. Moreover, its plane of polarization being that *perpendicular* to which the vibrations are performed, will necessarily pass through the axis, in which respect it also agrees with the ordinary ray, as actually observed.

Properties of the ordinary ray.

991. Properties of the extraordinary ray explained.

The extraordinary ray arises from the other resolved portion of the original vibration, which is performed in a plane parallel to the axis. By the principle of transverse vibrations, it is also performed in a plane perpendicular to the ray. If, then, we suppose a plane to pass through the extraordinary ray and the axis, it will cut a plane perpendicular to the ray in a straight line, which will be the direction of the vibratory motion. This direction, then, is inclined to the axis in an angle equal to the complement of that made by the extraordinary ray with the latter line, and therefore, when the extraordinary ray is parallel to the axis, the line of vibration is perpendicular to it, and *vice versâ*. In the former case, the elastic force resisting the displacement of the molecules is the same as in the case of the ordinary ray, and therefore the velocities of both rays are equal, and their directions coincide, and thus along the axis there is no separation of the rays. In the latter, the elasticity is that parallel to the axis, and therefore differing from the former by the greatest possible quantity. Here, then, the difference of velocities, and therefore of directions is at its maximum. In intermediate situations of the extraordinary ray, the elasticity developed is intermediate, and therefore also the velocity and double refraction. Thus we see, that according to this doctrine the difference of velocities, and consequent separation of the pencils should be nothing in the axis, and go on increasing till the extraordinary ray is at right angles to it, which is conformable to fact. Lastly, the plane of polarization of the extraordinary ray being at right angles to the plane of vibration, must also be at right angles to a plane passing through the ray and the axis, which is also conformable to fact.

992. The theory of M. Fresnel gives then, as we see, at least a plausible account of the phenomena of double refraction in the case of uniaxal crystals; and when we consider the profound mystery which, on every other hypothesis, was admitted to hang over this part of the subject, we must allow that this is a great and important step. But the same principles are equally applicable to biaxal crystals with proper modifications, and (which is a strong argument for their reality) lead, when so applied, to conclusions which, though totally at variance with all that had been taken for granted before, on the grounds of imperfect analogy and insufficient experiment, have been since verified by accurate and careful experiments, and have thus opened a new and curious field of optical inquiry Nothing stronger can be said in favour of an hypothesis, than that it enables us to anticipate the results of experiment, and to predict facts opposed to received notions, and mistaken or imperfect experience.

993. Explanation of the phenomena of movable polarization.

But before we enter on this, it may be right to show how the phenomenon on which the theory of movable polarization is founded, is accounted for by the doctrine of transverse vibrations. According to this theory, as soon as a polarized ray enters a crystal, it commences a series of alternate assumptions of one or other of two planes of polarization, in the azimuths 0° and 2 *i*, *i* being the inclination of the principal section to the plane of primitive polarization: the plane assumed being in azimuth 0°, when the thickness traversed is such as to render the interval of retardation of the ordinary on the extraordinary ray 0, or any whole number of undulations, and in azimuth 2 *i* when it is any whole odd number of semi-undulations. Suppose a ray polarized in the azimuth 0 to be incident perpendicularly on a crystallized lamina, having its principal section in the azimuth *i*, then it will be resolved into two, the vibrations of which are respectively performed in the principal section, and perpendicular to it. Consequently, if we represent by unity the amplitude of the original vibrations, those of the two resolved vibrations will be equal respectively to sin *i* and cos *i*. Now, the thickness of the plate being first supposed such as to render the interval of retardation an exact number of undulations, these rays will emerge from the lamina in exact accordance, and being parallel, the systems of waves of which they consist will run on together. Being polarized, however, in opposite planes they will neither destroy each other, nor produce a compound ray equal to their sum, but their resultant must be determined as in Art. 623. For we have here the case of rectilinear vibrations, in complete accordance, of given amplitudes, and making a given angle (90°,) so that the result there obtained is immediately applicable to this case, and the resultant vibration will be, first, rectilinear, so that the compound ray will appear wholly polarized in one plane: and, secondly, its amplitude will be, both in quantity and direction, the diagonal of a parallelogram whose sides are the amplitudes of the component vibrations. Consequently, it will be identical with that b whose resolution these were produced, and therefore the resultant, or emergent compound ray will be, in respe both of its polarization and intensity, precisely similar to the original incident one.

Case of complete accordance.

994. Fig. 197. Case of complete discordance.

When the difference of paths within the crystal is an exact odd multiple of half an undulation, the waves their egress from the posterior surface will be in complete discordance. But their resultant may still determined by the same rule, regarding either of the rays as negative, *i. e.* as having its vibrations execu in the opposite direction. For suppose the molecule C moving in the direction C P, with the velocity (fig. 197) at the entry of the ray, then the resolved velocities in the planes C O and C E will be represented in quantity and direction by C O and C E. But at their egress, the vibrations in the direction C E having gained or lost a half undulation on those in C O, if C O represent the quantity and direction of motion of the molecule C in that plane, C E′ equal and opposite to C E will represent its motion in the other plane, and this, combined with C O will compose, not the original motion C P, as in the former case, but C Q, making an equal angle with C O on the other side. The resultant ray, then, instead of being polarized in the plane of the incident one, (*i. e.* perpendicular to C P) will be polarized in a plane perpendicular to C Q, making an angle equal to P C Q ($= 2$ P C O $= 2\,i$) with C O.

995. When the difference of routes is neither an exact number of whole, or half undulations, the vibrations of the resultant ray (by Art. 621) will no longer be rectilinear, but elliptic; and in the particular case when the interval of retardation is a quarter or an odd number of quarter undulations, it will be circular. In this case, the emergent ray, varying its plane of vibration every instant, will appear wholly depolarized, so as to give two equal images by double refraction in all positions of the analysing prism.

996. Experiment exhibiting these several cases of interference.

These several consequences may be rendered strikingly evident by a delicate and curious experiment related by M. Arago. Let a polarized pencil, emanating from a single radiant point, be incident on a double rhomboid of Iceland spar, composed of two halves of one and the same rhomboid, superposed so as to have their principal sections at right angles to each other. Then the emergent rays will emanate as if from two points (see Art. 879) near each other, and polarized in opposite planes. Let these two cones of rays be received on an emeried glass, or in the focus of an eye-lens, so that the glass or field of view shall be illuminated at once by the light of both, which being oppositely polarized will exhibit no fringes or coloured phenomena, but merely a uniform illumination; and let all the light but that which falls on a single very small point of the field of view be stopped by a plate of metal, with a small hole in it, so as to allow of examining the state of polarization of the compound ray illuminating this point, separately from all the rest. Then it will be seen, on analysing its light by a tourmaline or double refracting prism, that, when the spot examined is distant from both radiants by the same number of undulations, although in fact composed of two rays oppositely polarized, (as may be proved by stopping one of them, and examining the other singly,) yet it presents the phenomenon of a ray completely polarized in one plane, which is neither that of the one or the other of its component rays, but the original plane of polarization of the incident light. Suppose now, by a fine screw we shift gradually the place of the metal plate so as to bring the hole a little to one or the other side of its former place. The ray which illuminates it will appear to lose its polarized character as the motion of the plate proceeds, and at length will offer no trace of polarization; continuing the motion, and bringing in succession other points of the field of view under examination, the light which passes through the hole will again appear polarized, at first partially, and at length totally; not, however, as before, in the plane of primitive polarization, but in a plane making with it twice the angle included between it and the principal section of the first rhomboid, and so on alternately. Thus we are presented with the singular phenomenon of two rays polarized in planes at right angles, which produce by their concourse a ray either wholly polarized in one or the other of two planes, or not polarized at all, according to the difference of routes of the rays before their union.

997. Fresnel's general theory of double refraction.

In 1821, M. Fresnel presented to the Academy of Sciences of Paris a Memoir, containing the general application of the principle of transverse vibrations to the phenomena of double refraction and polarization as exhibited in biaxal crystals, which was read in November of that year. A brief report on the experimental parts of this Memoir by the Committee of the Academy appointed to examine it, about half a dozen pages, was published in the *Annales de Chimie*, vol. xx. p. 337, recommending it to be printed as speedily as possible in the collection of the *Mémoires des Savans Etrangers.* We are sorry to observe, that this recommendation has not yet been acted upon, and that this important Memoir, to the regret and disappointment of men of science throughout Europe, remains yet unpublished; though we trust (from the activity recently displayed by the Academy in the publication of their Memoirs in arrear) this will not long continue to be the case.[*] An abstract by the author himself, which appeared in the *Bulletin de la Société Philomatique* of 1822, and was subsequently reprinted in the *Annales de Chimie*, 1825, enables us, however, to present a sketch, though an imperfect one, of its contents, supplying to the best of our ability the demonstration of the fundamental propositions, and reaping a melancholy gratification from the inadequate tribute, which, in thus introducing for the first time to the English reader a knowledge of these profound and interesting researches, we are enabled to pay to departed merit. *His saltem accumulem donis—et fungar inani munere.* For even at the moment when we are recording his discoveries, their author has been snatched from science in the midst of his brilliant career by a premature death, like his hardly less illustrious contemporary, Fraunhofer, the early victim of a weakly constitution and emaciated frame, unfit receptacles for minds so powerful and active.

998. General expression for the elastic forces of a medium investigated.

M. Fresnel assumes, as a postulatum, that the displacement of a molecule of the vibrating medium in a crystallized body (whether that medium be the ether, or the crystal itself, or both together, in virtue of some mutual action exercised by them on each other,) is resisted by different elastic forces, according to the different directions in which the displacement takes place. Now it is easy to conceive, that in general the resultant of all the molecular forces which act on a displaced molecule, is not necessarily parallel to the direction of its displacements when the partial forces are unsymmetrically related to this direction, but the proposition may be demonstrated *à priori*, as follows. Suppose three coordinates x, y, and z, to represent the partial displacements of any molecule M in their respective directions, and $r\ (=\sqrt{x^2+y^2+z^2})$ the total displacement, making angles α, β, γ, respectively with the axes of the x, y, z, so that $x = r \,.\, \cos\alpha$, $y = r \,.\, \cos\beta$, $z = r \,.\, \cos\gamma$. Now, since in this theory we assume that the displacements of the molecules are infinitely, or at least extremely small compared with the distances of the molecules *inter se*, it is evident that whatever be the law of molecular action, the force resulting from any displacement must (*cæteris paribus*) be proportional to the linear magnitude of that displacement, and can, therefore, be only of the form $r \,.\, \phi$, where ϕ is some unknown function of the angles α, β, γ, or their cosines. And, moreover, since such infinitely small displacements, in whatever direction made, neither alter the angular position, nor distance of the displaced molecule among the rest, by any sensible quantity, all their forces will act on it in its displaced position in the same manner as before. Hence the total force developed by the simultaneous displacements x, y, z, or by the single displacement r must be equivalent to (or the statical resultant of) the three which would be developed independently by the several partial displacements x, y, z. Now the force originating in the partial displacement x alone will result from $r\phi$ by making $r = x$ and ϕ equal to a, where a is the same function of 1, 0, 0, that ϕ is of $\cos\alpha$, $\cos\beta$, $\cos\gamma$. a therefore is a constant depending only on the position of the axes of the x, y, z with respect to the molecules of the crystal. And when this partial force $= a\,x$ is resolved into the directions of these several axes, since its direction (whatever it be) is determinate, the resolved portions can only be of the form $\mathrm{A}\,x$, $\mathrm{A}'\,x$, $\mathrm{A}''\,x$, where A, A′, A″ are in like manner dependent only on the position of the coordinates x, y, z with respect to the molecules, and not at all on α, β, γ, which are arbitrary, and where $\mathrm{A}^2 + \mathrm{A}'^2 + \mathrm{A}''^2 = a^2$. The same being true of the partial forces brought into play by the displacements y and z, it follows that the total force arising from the displacement r must be the resultant of the three forces

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[*] This delay has been productive of a singular consequence, which will suffice to show the small degree of publicity which labours, even the most important, can acquire by the circulation of such notices as those mentioned in the text. So lately as December 1826, the Imperial Academy of Sciences of Petersburg proposed as one of their prize questions for the two years 1827 and 1828, the following, "*To deliver the optical system of waves from all the objections which have (as it appears) with justice, been urged against it, and to apply it to the polarization and double refraction of light.*" In the programma announcing this prize, M. Fresnel's researches on the subject are not alluded to (though his *Memoir on Diffraction* is noticed,) and it is fair to conclude, were not then known to the Academy. Precisely one month before the publication of this programma, the Royal Society of London awarded their Rumford Medal to M. Fresnel, "for his application of the undulatory theory to the phenomena of polarized light, and for his important experimental researches and discoveries in physical optics." Our readers will be gratified to know, that the valuable mark of this high distinction reached him a few days before his death.

Principle of partial displacements.

$$f = \mathrm{A}\,x + \mathrm{B}\,y + \mathrm{C}\,z,\quad f' = \mathrm{A}'x + \mathrm{B}'y + \mathrm{C}'z,\quad f'' = \mathrm{A}''x + \mathrm{B}''y + \mathrm{C}''z,$$

respectively parallel to the axes of the x, y, z, where the coefficients are independent of α, β, γ, and where, in like manner, $\mathrm{B}^2 + \mathrm{B}'^2 + \mathrm{B}''^2 = b^2$, $\mathrm{C}^2 + \mathrm{C}'^2 + \mathrm{C}''^2 = c^2$. But we have $x = r \,.\, \cos\alpha$, $y = r \,.\, \cos\beta$, $z = r \,.\, \cos\gamma$, so that if we put

$$\begin{aligned} f &= r\ \{\mathrm{A} \,.\, \cos\alpha + \mathrm{B} \,.\, \cos\beta + \mathrm{C} \,.\, \cos\gamma\}, \\ f' &= r\ \{\mathrm{A}' \,.\, \cos\alpha + \mathrm{B}' \,.\, \cos\beta + \mathrm{C}' \,.\, \cos\gamma\}, \\ f'' &= r\ \{\mathrm{A}'' \,.\, \cos\alpha + \mathrm{B}'' \,.\, \cos\beta + \mathrm{C}'' \,.\, \cos\gamma\}, \end{aligned}$$

the resultant of f, f', f'' will be the force urging the displaced molecule.

999. Expression of the elasticity in any assigned direction.

Now these forces acting in the directions of the coordinates may each be decomposed into two, one in the direction of the displacement r, and the other at right angles to it in the planes respectively of r and x, r and y, r and z, the sum of the former will be

$$\mathrm{F} = f \,.\, \cos\alpha + f' \,.\, \cos\beta + f'' \,.\, \cos\gamma,$$

Acts obliquely to the direction of displacement.

which is the whole force tending to urge the displaced molecule directly to its position of equilibrium. The latter will be respectively equal to $f \,.\, \sin\alpha$, $f' \,.\, \sin\beta$, and $f'' \,.\, \sin\gamma$; but as they act, although in one plane, yet not in the same direction, they will not destroy each other, unless they be to each other in the ratio of the sines of the angles they make with each other's direction. But it is evident, that since α, β, γ are arbitrary, this condition cannot hold good in general, because it furnishes two equations, which, taken in conjunction with the relation $\cos\alpha^2 + \cos\beta^2 + \cos\gamma^2 = 1$, suffice to determine α, β, γ. Hence it follows, that *the displaced molecule is, except in certain cases, urged by the elastic forces of the medium obliquely to the direction of its displacement.*

1000. Axes of elasticity defined and investigated

Mr. Fresnel next goes on to observe, that in general *every elastic medium has three rectangular axes, in the direction of which, if a molecule be displaced, the resultant of the molecular forces urging it will act in the direction of its displacement.* These are the excepted cases just alluded to, and to the axes possessing this property, (which he regards as the true fundamental axes of the crystal,) he gives the name of *Axes of Elasticity.*

To demonstrate this proposition we must observe, that, by mechanics, in order that the resultant of three rectangular forces f, f', f'' shall make angles α, β, γ with their three directions, and therefore be coincident in direction with r, they must be to each other in the ratio of the cosines of these angles, and therefore we must have the following equations expressive of this condition,

$$\frac{f}{f'} = \frac{\cos\alpha}{\cos\beta};\quad \frac{f}{f''} = \frac{\cos\alpha}{\cos\gamma};\quad \frac{f'}{f''} = \frac{\cos\beta}{\cos\gamma}.$$

These three equations are in general equivalent to two only, but when combined with the equation $\cos\alpha^2 + \cos\beta^2 + \cos\gamma^2 = 1$ resulting from the geometrical conditions of the case, they suffice to determine α, β, and γ; and if we put u, v, w for the cosines of these angles, furnish the following system of equations which every axis of elasticity must satisfy.

$$\begin{aligned} (\mathrm{A}\,u + \mathrm{B}\,v + \mathrm{C}\,w)\,v &= (\mathrm{A}'u + \mathrm{B}'v + \mathrm{C}'w)\,u, \\ (\mathrm{A}\,u + \mathrm{B}\,v + \mathrm{C}\,w)\,w &= (\mathrm{A}''u + \mathrm{B}''v + \mathrm{C}''w)\,u, \\ (\mathrm{A}'u + \mathrm{B}'v + \mathrm{C}'w)\,w &= (\mathrm{A}''u + \mathrm{B}''v + \mathrm{C}''w)\,v, \\ u^2 + v^2 + w^2 &= 1. \end{aligned}$$

1001. Suppose by elimination we have derived from these equations the position of one axis of elasticity, then it will follow of necessity, that two others must exist, at right angles to it and to each other. To prove this, we must consider the connection between the partial forces developed by any displacement of the molecule M, and the molecular attractions and repulsions of the medium. Let ϕ be the action of any molecule $d\,m$ on M, which we suppose to be exerted in the direction of their line of junction, and to be a function of their mutual distance ρ. Then, if we suppose M displaced by any arbitrary quantities δx, δy, δz (infinitely small in comparison with ρ) in the direction of the three coordinates, we have

Three exist in any crystal at right angles to each other.

$$\delta\phi = \left(\frac{x}{\rho}\delta x + \frac{y}{\rho}\delta y + \frac{z}{\rho}\delta z\right) \cdot \frac{d\phi}{d\rho},$$

and putting $\phi' = \frac{d\phi}{d\rho}$, and $\frac{x}{\rho} = \cos\lambda$, $\frac{y}{\rho} = \cos\mu$, $\frac{z}{\rho} = \cos\nu$,

we have $\delta\phi = \phi' . \, \delta x . \cos\lambda + \delta y . \cos\mu + \delta\rho . \cos\nu \} .$

Consequently, since the force of the molecule $d\,m$, resolved into the directions of the coordinates, is respectively equal to

$$(\phi + \delta\phi)\, d\,m . \frac{x}{\rho}, \quad (\phi + \delta\phi)\, d\,m . \frac{y}{\rho}, \quad \text{and } (\phi + \delta\phi)\, d\,m . \frac{z}{\rho},$$

the sum of all these throughout the medium will be the total action on M; but since in the original position of the molecule M it is in equilibrio, we have

$$\int \phi\, d\,m . \frac{x}{\rho} = 0, \quad \int \phi\, d\,m . \frac{y}{\rho} = 0, \text{ and } \int \phi\, d\,m . \frac{z}{\rho} = 0,$$

so that the whole action of the medium on M in its displaced situation will be, in the three directions

General relation between the partial elasticities.

$$\int \frac{x}{\rho}\, d\,m . \delta\phi, \quad \int \frac{y}{\rho}\, d\,m . \delta\phi, \quad \int \frac{z}{\rho}\, d\,m . \delta\phi;$$

that is, in the direction of the x,

$$\int \phi'\, d\,m . \{ \cos\lambda^2\, \delta x + \cos\mu^2 . \delta y + \cos\nu^2 . \delta z \};$$

δx, δy, δx, are the partial displacements of M in the directions of the coordinates, and are, therefore, the same we denoted in Art. 998 by x, y, z. Restoring these denominations, we see that, on this hypothesis, (the most natural which can be formed respecting the mode of molecular action) the coefficients A, B, C, can be no other than the following,

$$\text{A} = \int \phi'\, d\,m . \cos\lambda^2, \quad \text{B} = \int \phi'\, d\,m . \cos\lambda . \cos\mu, \quad \text{C} = \int \phi'\, d\,m . \cos\lambda . \cos\nu;$$

and by similar reasoning we find

$$\text{A}' = \int \phi'\, d\,m . \cos\lambda . \cos\mu, \quad \text{B}' = \int \phi'\, d\,m . \cos\mu^2, \quad \text{C}' = \int \phi'\, d\,m . \cos\mu . \cos\nu;$$
$$\text{A}'' = \int \phi'\, d\,m . \cos\lambda . \cos\nu, \quad \text{B}' = \int \phi'\, d\,m . \cos\mu . \cos\nu, \quad \text{C}'' = \int \phi'\, d\,m . \cos\nu^2;$$

and, consequently, the following relations must necessarily subsist between these coefficients

$$\text{B} = \text{A}', \quad \text{C} = \text{A}'', \quad \text{C}' = \text{B}''.$$

1002. This premised, suppose we have determined one axis of elasticity of the medium by the foregoing equations. Since the positions of the axes of the coordinates are arbitrary, we are at liberty to suppose that of the x coincident with the axis so determined, which renders $\text{A}' = \text{A}'' = 0$, and consequently $\text{B} = 0$ and $\text{C} = 0$, and $\text{B}'' = \text{C}'$, because the relations above demonstrated are general and independent of any particular situation of the axes. The equations of Art. 1000 then become

One axis being given the situation of the other determined.

$$\text{A}\, u\, v = (\text{B}'\, v + \text{C}'\, w)\, u, \quad \text{A}\, u\, w = (\text{B}''\, v + \text{C}''\, w)\, v,$$
$$(\text{B}'\, v + \text{C}'\, w)\, w = (\text{C}'\, v + \text{C}''\, w)\, v, \quad u^2 + v^2 + w^2 = 1.$$

Now if we put $u = 0$, or $a = 90°$, the two former of these are satisfied without any relation supposed between v and w, so that if we determine these from the two latter only, the whole system will be satisfied. These (making $u = 0$) give at once by elimination

$$w = \sqrt{\frac{1}{2}\left(1 \pm \frac{1}{\sqrt{4\,m^2 + 1}}\right)}; \quad v = -\sqrt{\frac{1}{2}\left(1 \mp \frac{1}{\sqrt{4\,m^2 + 1}}\right)},$$

where $m = \frac{\text{C}'}{\text{B}' - \text{C}''}$. Now since m^2 is necessarily positive, $4\,m^2 + 1$ is so, and is > 1; therefore $\frac{1}{\sqrt{4\,m^2 + 1}}$ is real and < 1, consequently w^2 and v^2 are both positive, and therefore v and w both real, and less than unity. Hence it follows, that there are necessarily two axes at right angles to the x which satisfy the conditions of axes of elasticity, and the opposite signs of v and w show that they are at right angles to each other.

1003. For simplicity, therefore, we will in future suppose the directions of the coordinates to be coincident with those of the axes of elasticity, so as to make

$$A = a,\ A' = A'' = 0;\quad B' = b,\ B = B'' = 0;\quad C'' = c,\ C = C' = 0;$$

then we have by Art. 998 for the partial forces,

$$f = a\,x = a\,r\,.\cos\alpha,\quad f' = b\,y = b\,r\,.\cos\beta,\quad f'' = c\,z = c\,r\,.\cos\gamma,$$

and by 999,

$$F = r\ \{a\,.\cos\alpha^2 + b\,.\cos\beta^2 + c\,.\cos\gamma^2\}$$

for the whole force urging the molecule M in the direction of the r, generally assumed, in which it will be observed that

$$a = \int\phi'\,.\cos\lambda^2\,d\,m,\quad b = \int\phi'\,.\cos\mu^2\,d\,m,\quad c = \int\phi'\,.\cos\nu^2\,d\,m.$$

1004. *The surface of elasticity* defined and investigated.

M. Fresnel next conceives a surface, which he terms the "Surface of Elasticity," constructed according to the following law:—on each of the *axes of elasticity*, and on every radius r drawn in all directions, take a length proportional to the square root of the elasticity exerted on the displaced molecule by the medium in the direction of the radius, or to $\sqrt{F}$. Then if we call R this length, or the radius vector of the surface of elasticity, we shall have

$$R^2 = \{a\,r\,.\cos\alpha^2 + b\,r\,.\cos\beta^2 + c\,r\,.\cos\gamma^2\} \times \text{const.}$$

Its radius vector expressed.

The values of R parallel to the axes are then had by the equation

$$R^2 = \text{const}\ a\,r,\quad R^2 = \text{const} \times b\,r,\quad R^2 = \text{const} \times c\,r$$

which (for brevity, as we shall have no further occasion to recur to our former denominations) we shall express simply by a^2, b^2, c^2, so that the equation of the surface of elasticity will be of the form

$$R^2 = a^2\,.\cos X^2 + b^2\,.\cos Y^2 + c^2\,.\cos Z^2,$$

where X, Y, Z, now stand for α, β, γ, the angles made by R with the axes of the coordinates.

1005. Velocity and plane of polarization of an interior wave determined.

Let us now imagine a molecule displaced and allowed to vibrate in the direction of the radius R, and retained in that line, or at least let us neglect all that part of its motion which takes place at right angles to the radius vector. Then the force of elasticity by which its vibrations are governed will be proportional to R^2, and the velocity of the luminous wave propagated by means of them, in a direction transverse to them (or at right angles to R) will be proportional to R, so that the surface of elasticity being known, the velocity of a wave transmitted through the medium in a given direction, and with a given plane of polarization will be had at once as follows. Parallel to the surface of the wave, and at right angles to its plane of polarization draw a straight line. This will be the direction of the vibrations by which the wave is propagated. Parallel to this line draw a radius vector to the surface of elasticity, and it will represent the wave's velocity.

1006. Equation of the surface of elasticity.

The equation of the surface of elasticity, if we put for R, cos X, cos Y, cos Z, their values in terms of three coordinates will become

$$(x^2 + y^2 + z^2)^2 = a^2\,x^2 + b^2\,y^2 + c^2\,z^2.$$

It is, therefore, in general a surface of the fourth order. If we suppose it cut by a plane passing through its centre, whose equation must therefore in general be of the form $m\,x + n\,y + p\,z = 0$, the curve of intersection will be a species of oval whose diameters are not necessarily all equal.

1007. Resolution of an incident wave into two.

Suppose now any molecule set in vibration in this plane, then at any period of its motion it will not be urged directly to its point of rest but obliquely, so that it will not describe a straight line, but will circulate in a curve more or less complicated; its motion in this, however, will always be resolvable into two vibratory rectilinear ones at right angles to each other, one parallel to the greatest, and the other to the least diameter of the section. Each of these vibratory motions will, by the laws of motion, be performed independently of the other, and therefore the motion propagated through the crystal will affect every molecule of it in the same way as if two separate and independent rectilinear vibrations (at right angles as above) were propagated through it, with different velocities. Consequently every system of waves propagated from without into the crystal, will necessarily on entering it be resolved into two propagated with different velocities, and polarized in planes at right angles to each other, *viz.* those parallel respectively to the greatest and least diameter of a section of the surface of elasticity parallel to the plane of either wave. And as every difference in the velocities of two waves propagated parallel to each other through a medium, gives rise to a corresponding difference in their planes at their emergence from it into another, where they assume a common velocity, these waves will at their egress no longer be parallel, and the rays which are perpendicular to them will be inclined to each other, thus producing the phenomena of double refraction; and it is evident that the waves at their egress must retain the planes of polarization they received in the crystal, because any molecule of the exterior medium at the junction of the media will begin to move only in the plane in which it was displaced by the contiguous molecule in the medium.

Polarized in opposite planes.

1008. This theory then accounts perfectly both for the bifurcation of the emergent ray, and the opposite polarizations of the two portions into which it is divided. These portions will coincide in direction, and there will be no double refraction when the section of the surface of elasticity above mentioned is (if such can ever be the case) a circle, because all its radii being then equal, the elasticity is the same in all directions, and all vibrations performed in it will have equal periods, so that in this case the resolution of the incident wave into two no longer takes place, nor is its plane of polarization changed. Now the section in question becomes a circle, when $x^2 + y^2 + z^2 = \text{const} = r^2$, or when $a^2\,x^2 + b^2\,y^2 + c^2\,z^2 = r^4$. Combining these with $m\,x + n\,y + p\,z = 0$, we get

$$r^4 = r^2 (x^2 + y^2 + z^2),$$

$$p^2 r^4 = r^2 (p^2 x^2 + p^2 y^2 + (m x + n y)^2),$$

and

$$p^2 r^4 = p^2 a^2 x^2 + p^2 b^2 y^2 + c^2 (m x + n y)^2,$$

and equating these, and considering that the equation thence resulting ought to be verified independently of any particular values of x, y, we get

Investigation of the optic axes.

$$r^2 (m^2 + p^2) = a^2 p^2 + m^2 c^2,$$

$$m n r^2 = m n c^2,$$

$$r^2 (p^2 + n^2) = b^2 p^2 + n^2 c^2.$$

These equations cannot be satisfied except by supposing either m, n, or p to vanish, or the section in question to pass through one or other of the axes. If we suppose $m = 0$, we have $r = a$, $\left(\frac{n}{p}\right)^2 = \frac{a^2 - b^2}{c^2 - a^2}$, which shows that $\left(\frac{n}{p}\right)^2$ cannot be positive, and of course $\frac{n}{p}$ not real, unless a, the semiaxis of the surface through which the section passes, be that intermediate in length between b and c, the other two semiaxes.

1009 It appears then, that the surface of elasticity admits of two circular sections and no more, formed by diametral planes passing through the mean axis of the surface, and (since $\frac{n}{p}$ has two values equal but of opposite signs) that these sections are both equally inclined to each of the other two axes. The normals to these sections are the directions of no double refraction, or the *optic axes* of the crystal. Of these, then, there will be two and two only, in all crystals which possess three unequal axes of elasticity, and rays propagated along them will suffer neither double refraction, nor change of polarization.

1010. Dispersion of the axes of different colours explained.

The position of these axes depends wholly on the values of a, b, c, the semiaxes of the surface of elasticity. We have, however, no other measure of the elasticity of the medium than the velocity with which the rays are propagated through it; and if, as the phenomena of ordinary dispersion indicate, the rays of different colours be propagated in one and the same medium with velocities somewhat different, (an effect which might result from certain suppositions relative to the extent of the sphere of action of its molecules compared with the lengths of an undulation,) the semiaxes a, b, c, which must be taken proportional to the velocities of propagation, must be supposed to vary a little for waves of different lengths. Now this variation may not be in the same ratio for all the three semiaxes, and thus a variation in the values of $\frac{n}{p}$ will arise. But $\frac{n}{p}$ is the tangent of the inclination of the plane of section to the plane of the $x\,y$, or of half the angle the two circular sections make with each other, *i. e.* the cotangent of half the angle between the optic axes, which will thus vary, and give rise to that separation of axes of different colours, and their distribution over a certain angle, *in the plane containing any two* of the same colour, which observation shows to exist, (Art. 921 and 922.)

1011. Application of the Huygenian construction to the general case.

The general laws of double refraction flow with great facility from these principles. We have only to resume the construction and reasoning of Art. 806 and 807, *et seq.*, substituting for the ellipsoid of revolution, which the Huygenian theory assumes as the figure of a wave originating in any molecule of the crystal, the surface, whatever it be, which, in the general case, terminates a wave so propagated, and investigating the point of contact I (fig. 170) of this surface with a plane I K T passing through the line K T drawn as there described. There is this difference, however, in the two cases, or, at least, in the method of treating them, that in the theory there stated the form of the wave is made a matter of arbitrary assumption, in the present case it is to be determined *à priori.* This will render it necessary to depart in some respects from the course before adopted. If we know, *à priori,* the form of the wave, the position of the tangent plane is given; *vice versâ,* if we can determine the position of this plane in all cases, *à priori,* the figure of the wave, which must be such as to touch all such planes, under the conditions of the case, becomes known.

1012 Direction and velocity of a plane wave.

Now, in Art. 807, it is shown that the tangent plane is in all cases coincident with the position assumed within the crystal, by the surface of a plane indefinite wave propagated from an infinitely distant luminary, perpendicular to the line of incidence R C. It follows, moreover, from Art. 811, that if we know the velocity with which such a plane wave advances within the crystal in a direction perpendicular to its surface, we may calculate its inclination to the surface of incidence by the law of ordinary refraction, assuming an index of refraction which is to that of the ambient medium as the velocity of the wave before incidence is to its velocity within the medium perpendicular to its own surface. The reader will here keep in view the distinction noticed in Art. 813 between the velocity of the *wave* and that of the *ray* conveyed by it, whose direction, generally speaking, is oblique to its surface. Now the velocity of a wave within the medium in any direction is given by the equation of the surface of elasticity, whose radius vector expresses it in all cases. But it has been shown, that every vibration impressed on the molecules of the crystal is resolved into two rectilinear ones propagated with velocities proportional to the greatest and least diameters of that section of the surface of elasticity which is parallel to the plane in which they are performed. Now it is the same thing, (as far as the law of double refraction is concerned,) whether we regard the bifurcation to take place by the separation of a single exterior ray into two interior ones, or a single interior into two exterior. We will take the latter case, and suppose the

$$A = a,\ A' = A'' = 0;\quad B' = b,\ B = B'' = 0;$$

then we have by Art. 998 for the partial forces,

$$f = a\,x = a\,r\,.\cos\alpha,\quad f' = b\,y = b\,r\,.\cos\beta,\quad f'' = c\,z = c\,r\,.\cos\gamma,$$

and by 999,

$$F = r\ \{a\,.\cos\alpha^2 + b\,.\cos\beta^2 + c\,.\cos\gamma^2\}$$

for the whole force urging the molecule M in the direction of the r, generally assumed, in which it will be observed that

$$a = \int\phi'\,.\cos\lambda^2\,d\,m,\quad b = \int\phi'\,.\cos\mu^2\,d\,m,\quad c = \int\phi'\,.\cos\nu^2\,d\,m.$$

1004. **The *surface of elasticity* defined and investigated.** M. Fresnel next conceives a surface, which he terms the " Surface of Elasticity," constructed according to the following law :—on each of the *axes of elasticity*, and on every radius r drawn in all directions, take a length proportional to the square root of the elasticity exerted on the displaced molecule by the medium in the direction of the radius, or to $\sqrt{F}$. Then if we call R this length, or the radius vector of the surface of elasticity, we shall have

$$R^2 = \{a\,r\,.\cos\alpha^2 + b\,r\,.\cos\beta^2 + c\,r\,.\cos\gamma^2\} \times \text{const.}$$

Its radius vector expressed. The values of R parallel to the axes are then had by the equation

$$R^2 = \text{const}\ a\,r,\quad R^2 = \text{const} \times b\,r,\quad R^2 = \text{const} \times c\,r$$

which (for brevity, as we shall have no further occasion to recur to our former denominations) we shall express simply by a^2, b^2, c^2, so that the equation of the surface of elasticity will be of the form

$$R^2 = a^2\,.\cos X^2 + b^2\,.\cos Y^2 + c^2\,.\cos Z^2,$$

where X, Y, Z, now stand for α, β, γ, the angles made by R with the axes of the coordinates.

1005. **Velocity and plane of polarization of an interior wave determined.** Let us now imagine a molecule displaced and allowed to vibrate in the direction of the radius R, and retained in that line, or at least let us neglect all that part of its motion which takes place at right angles to the radius vector. Then the force of elasticity by which its vibrations are governed will be proportional to R^2, and the velocity of the luminous wave propagated by means of them, in a direction transverse to them (or at right angles to R) will be proportional to R, so that the surface of elasticity being known, the velocity of a wave transmitted through the medium in a given direction, and with a given plane of polarization will be had at once as follows. Parallel to the surface of the wave, and at right angles to its plane of polarization draw a straight line. This will be the direction of the vibrations by which the wave is propagated. Parallel to this line draw a radius vector to the surface of elasticity, and it will represent the wave's velocity.

1006. **Equation of the surface of elasticity.** The equation of the surface of elasticity, if we put for R, cos X, cos Y, cos Z, their values in terms of three coordinates will become

$$(x^2 + y^2 + z^2)^2 = a^2\,x^2 + b^2\,y^2 + c^2\,z^2.$$

It is, therefore, in general a surface of the fourth order. If we suppose it cut by a plane passing through its [illegible] centre, whose equation must therefore in general be of the form $m\,x + n\,y + p\,z = 0$, the curve of intersection [illegible] will be a species of oval whose diameters are not necessarily all equal.

1007. **Resolution of an incident wave into two.** Suppose now any molecule set in vibration in this plane, then at any period of its motion it will not be urged [illegible] directly to its point of rest but obliquely, so that it will not describe a straight line, but will circulate in a curve [illegible] more or less complicated; its motion in this, however, will always be resolvable into two vibratory rectilinear ones at [illegible] right angles to each other, one parallel to the greatest, and the other to the least diameter of the section. Each of [illegible] these vibratory motions will, by the laws of motion, be performed independently of the other, and therefore the motion [illegible] propagated through the crystal will affect every molecule of it in the same way as if two separate and independent [illegible] vibrations (at right angles as above) were propagated through it, with different velocities. Consequently [illegible] propagated from without into the crystal, will necessarily on entering it be resolved into two [illegible] and polarized in planes at right angles to each other, *viz.* those parallel [illegible] section of the surface of elasticity parallel to the plane of

$= \sin a . \sin \beta . \sin x . \sin C - \cos \beta . \cos x,$

, since O B Q = 90° + O B A, we obtain a second relation

$= \sin a . \sin \beta . \sin x . \sin C + \cos \beta . \cos x;$

ng, for brevity's sake, $\cos \theta' = p$, $\cos \theta = q$,)

s $\beta . \cos x$; $p - q = 2 . \sin a . \sin \beta . \sin x . \sin C.$

etrical relations subsisting between the lines P C, Q C, and the axes A C, B C;

ions of Art. 1028 and 1029, suffice to eliminate a, β, and C, and to express

To execute this, we have by the equations just demonstrated

$$\Big)^2 = \cos \beta^2; \qquad \left(\frac{p-q}{2 . \sin x}\right)^2 = \sin a^2 . \sin \beta^2 . \sin C^2;$$

cos C² for sin C², and for cos C² its value given by Art. 1028, which, since $\gamma =$

$$\sin a^2 . \sin \beta^2 . \cos C^2 = \cos a^2 . \cos \beta^2,$$

$$\left(\frac{p-q}{2 . \sin x}\right)^2 = \sin a^2 . \sin \beta^2 - \cos a^2 . \cos \beta^2,$$
$$= \sin a^2 - \cos \beta^2.$$

of sin a^2 and sin β^2,

$$\sin a^2 = \left(\frac{p+q}{2 . \cos x}\right)^2 + \left(\frac{p-q}{2 . \sin x}\right)^2,$$

$$\sin \beta^2 = 1 - \left(\frac{p+q}{2 . \cos x}\right)^2;$$

ation of Art. 1029,

$$\frac{b}{\cos x^2}(p+q)^2 + \frac{a}{4 . \sin x^2}(p-q)^2 \Big\}^2 - \frac{a\,b}{\sin x^2}(p-q)^2.$$

pression for the tint, when referred to arbitrary axes in the manner here sup-

gh; but if we fix the position of the new axes so as to make $\sin x^2 = \frac{a}{b}$

ave then $\frac{a}{4 . \sin x^2} = \frac{b}{4}$, and $\frac{a-b}{4 . \cos x^2} = \frac{b}{4}$, so that the value of

$$1 - \left(\frac{p+q}{2}\right)^2 + \left(\frac{p-q}{2}\right)^2\Big)^2 - (p-q)^2\Big\},$$

$$- p\,q)^2 - (p-q)^2\} = b^2\{1 - p^2 - q^2 + p^2 q^2\},$$

$$p^2)(1 - q^2) = b^2 . \sin \theta^2 . \sin \theta'^2,$$

θ' and $\cos \theta$, consequently

$$T = - b . \sin \theta . \sin \theta'.$$

son stated further on in Art. 1034.

of the two axes in the manner here supposed, on Dr. Brewster's prin- 103

matic lines arranged in the form of sphero-lemniscates about two poles

$$B Q = \sqrt{\frac{\text{intensity of the feebler axis}}{\text{intensity of the stronger}}};$$

therefore the character of the optic axes in biaxal crystals, and may

ne of resultant axes. We must be careful, however, not to confound

ry.

1032. **Combination of a positive with a negative axis.**

denomination, as if one be positive and the other negative, the

ts cannot be so arranged. But if we suppose the new axes to

rizing ones, as in fig. 200, all other things remaining, we

and $\cos O B A = - \cos O B P$,

$- \cos \theta'$,

Velocities of an ordinary and extraordinary plane wave investigated.

ordinary and extraordinary plane waves to be parallel *within* the medium. Their velocities may then be investigated as follows: the equation of the surface of elasticity being

$$R^4 = a^2 x^2 + b^2 y^2 + c^2 z^2,$$

if we take, for the equation of the second plane,

$$z = m\,x + n\,y,$$

and put V for the maximum or minimum radius vector of the surface in the section in question, V will be the value of R, which makes $d\,R = 0$, and therefore will be given by elimination from the following system of equations

$$\begin{aligned} V^2 &= x^2 + y^2 + z^2, \\ V^4 &= a^2 x^2 + b^2 y^2 + c^2 z^2, \\ z &= m\,x + n\,y, \end{aligned}$$

and their differentials, regarding V as constant. This elimination, which is complicated enough, must be conducted as follows: first, if among the differential equations we eliminate $d\,x$, $d\,y$, $d\,z$; and for z in the whole system substitute its value, we shall get, putting $p = a^2 - b^2$; $q = a^2 - c^2$; $r = b^2 - c^2$;

$$\begin{aligned} V^4 &= (a^2 + m^2 c^2)\,x^2 + (b^2 + n^2 c^2)\,y^2 + 2\,m\,n\,c^2\,x\,y, \\ V^2 &= (1 + m^2)\,x^2 + (1 + n^2)\,y^2 + 2\,m\,n\,x\,y, \\ 0 &= m\,n\,q\,x^2 - m\,n\,r\,y^2 + k\,x\,y, \end{aligned}$$

where

$$k = p + n^2 q - m^2 r = (1 + n^2)\,q - (1 + m^2)\,r.$$

These, by elimination, give the following, in which

$$M = k^2 + 4\,m^2 n^2 q\,r;$$

$$\begin{aligned} M\,x^2 &= V^2 (V^2 - c^2) \{ (1 + n^2)\,k + 2\,m^2 n^2 r \} - r\,k\,V^2, \\ M\,y^2 &= -\,V^2 (V^2 - c^2) \{ (1 + m^2)\,k - 2\,m^2 n^2 q \} + r\,q\,V^2, \\ M\,x\,y &= -\,m\,n \{ (1 + n^2)\,q + (1 + m^2)\,r \} V^2 (V^2 - c^2) + 2\,m\,n\,q\,r\,V^2; \end{aligned}$$

and by equating the square of the last of these to the product of the two first, we find, after all reductions, th following equation for determining V:

$$(V^2 - a^2)(V^2 - b^2) + m^2 (V^2 - b^2)(V^2 - c^2) + n^2 (V^2 - a^2)(V^2 - c^2) = 0.$$

1013. General equation of a wave propagated from a point in the medium.

The roots of this equation determine the maximum and minimum values of the radius vector in the plane o section, and therefore the velocities of ordinary and extraordinary plane waves moving parallel to each othe within the crystal, and these found, the figure of the wave becomes known, from the condition that its surface must always be a tangent to a plane distant by the quantity V from the secant plane whose equation is $z = m\,x + n\,y$; and that, whatever be the values of m and n. Its investigation is therefore reduced to a purely geometrical problem. Required the equation of a curve surface, which shall touch every plane parallel to a plane whose equation is $z = m\,x + n\,y$; and distant from it by a quantity V, a function of m and given by the above equation, which, being resolved, will be found to lead to the following equation

$$\left.\begin{aligned} (a^2 x^2 + b^2 y^2 + c^2 z^2)(x^2 + y^2 + z^2) - a^2 (b^2 + c^2)\,x^2 - b^2 (a^2 + c^2)\,y^2 \\ -\,c^2 (a^2 + b^2)\,z^2 + a^2 b^2 c^2 \end{aligned}\right\} = 0.$$

1014. Nonexistence of the Cartesian law of refraction in biaxal crystals.

The surface represented by this equation is, generally speaking, of the fourth order, and consists of two distinct surfaces, or sheets, (*nappes.*) One of these, by its contact with the plane in question, determines the direction of the ordinary, and the other of the extraordinary ray. Now, it is important to remark, that this equation, so long as particular values are not assigned to a, b, c, is not decomposable into quadratic factors, so that neither of the sheets of which it consists is spherical, or ellipsoidal; and, consequently, neither the ordinary nor the extraordinary ray follows either the Cartesian or Huygenian law of refraction. This is a consequence too remarkable not to have been put to the test of experiment. Two methods have been put in practice by M. Fresnel for this purpose. The first consisted in measuring directly the velocities of the two rays in plates of topaz cut in different directions with respect to their axes by the method explained under the head of interferences, (Art. 738 and 739.) Since a difference of velocity of the interfering rays displaces the diffracted fringes as a difference of thickness would do, it is manifest that if, in two plates differently cut, but of precisely the same thickness, the fringes formed by the ordinary rays are differently displaced when the plates are combined successively with one and the same equivalent plate of glass, or any other standard medium, their velocity cannot be the same in both plates; and if such difference be observed to take place, both in the fringes formed by the interference of the ordinary and of the extraordinary rays severally, with a compensated pencil, it is clear that neither can have a constant velocity. Now the condition of equal thickness is secured by cementing the two plates edge to edge, and grinding and polishing them together, and carefully examining the surfaces after the operation, to be satisfied of their precise continuity, which may be done by the reflected image of a distant object, and yet more delicately by pressing slightly on them a convex lens of long focus, over their line of junction. If the coloured rings formed between the surfaces be uninterrupted, we are sure that this condition

This important fact has been lately ascertained by M. Mitscherlich, and we shall presently have occasion to speak further of it. From all these reasons it follows, that we can regard them only as resultant lines, to which no *à priori* properties can be supposed to belong, but which simply satisfy the condition $v - v' = 0$, according to the laws which regulate the constitutions of the functions v, v', the velocities of the two rays, in terms of those quantities which we may regard as fundamental data, and the situation of the ray within the medium. The axes of elasticity themselves may, perhaps, be regarded as mere resultants from the equations of Art. 1000, and determined from other remoter data dependent on the fundamental lines in the crystalline form, and the intensity and distribution of the molecular forces within it. Accordingly, Dr. Brewster considers the optic axes as the resultants of others which he terms *polarizing axes*, and from which he conceives to *emanate* polarizing *forces* producing the phenomena of the rings and of the double refraction and polarization observed. We shall not here stop to examine into the propriety of these terms. The reader who may have doubts on the subject will, in what follows, mentally substitute other and more general phrases in their place expressive of relation and causality, while we proceed to state the assumptions with which he sets out, and the conclusions he very ingeniously deduces from them.

1021. A single polarizing axis. *Postulate* 1. A polarizing axis, when single, has the characters of an axis of no double refraction, and is coincident with the axis of the Huygenian spheroid in such crystals as have but one. A positive axis acts as the axis in quartz, &c. may be supposed to do, and a negative, as that of carbonate of lime, &c.

1022. Polarizing force. *Post.* 2. The polarizing force of a single axis in any medium is proportional to, and measured by, the tint developed in the ordinary and extraordinary pencils into which a doubly refracting prism analyzes a polarized ray, which has traversed a given thickness of the medium.

1023. *Corol.* 1. The polarizing force of a single axis in the same medium is as the square of the sine of the angle made by the ray traversing it internally, with the axis.

1024. *Corol.* 2. The same force is also inversely as the thickness necessary to be traversed at a given angle to develope the same or equal tints. This may be regarded as the *intrinsic* polarizing force or *intensity* of the axis.

1025. Composition of tints in the case of two axes. *Post.* 3. When two axes exist in one medium and operate together, they polarize a tint whose measure (see Art. 906) is the diagonal of a parallelogram whose sides measure, on the same scale, the tints which would be polarized by either, separately, and include between them an angle *double* of the mutual inclination of two planes passing through the ray and either axis respectively.

1026. Formula for the compound tint. *Corol.* 1. If t and t' be the numerical measures of the tints polarized by either of two axes separately, T that polarized by their joint action, and C the angle between the planes just described, the tint T will be given by the equation

$$T^2 = t^2 + 2\,t\,t' . \cos 2\,C + t'^2.$$

1027. *Corol.* 2. If a and b represent the intensities of the axes, and α and β the angles which the ray makes with each respectively, we have $t = a . \sin \alpha^2$; $t' = b . \sin \beta^2$, and

$$T^2 = (a . \sin \alpha^2)^2 + (b . \sin \beta^2)^2 + 2\,a\,b . \sin \alpha^2 . \sin \beta^2 . (1 - 2 . \sin C^2),$$

$$= \{ a . \sin \alpha^2 + b . \sin \beta^2 \}^2 - 4\,a\,b . \sin \alpha^2 . \sin \beta^2 . \sin C^2,$$

or else

$$T^2 = \{ a . \sin \alpha^2 - b . \sin \beta^2 \}^2 + 4\,a\,b . \sin \alpha^2 . \sin \beta^2 . \cos C^2.$$

1028. If γ be the angle contained between the polarizing axes, since α, β, γ are the sides of a spherical triangle, and C the angle included between the sides α and β, or opposite to γ, we have

$$\cos C = \frac{\cos \alpha . \cos \beta - \cos \gamma}{\sin \alpha . \sin \beta},$$

and if this be written for cos C in the latter of the expressions above given for T^2, we find on reduction

$$T^2 = \{ a . \sin \alpha^2 + b . \sin \beta^2 \}^2 - 4\,a\,b \{ 1 - \cos \alpha^2 - \cos \beta^2 - \cos \gamma^2 + 2 . \cos \alpha . \cos \beta . \cos \gamma \}.$$

1029. *Corol.* If the polarizing axes be at right angles to each other, $\gamma = 90°$ and $\cos \gamma = 0$, and the expression for the compound tint becomes

$$T^2 = \{ a . \sin \alpha^2 + b . \sin \beta^2 \}^2 - 4\,a\,b\,(\sin \alpha^2 - \cos \beta^2).$$

1030. *Proposition. Two rectangular polarizing axes, either both positive or both negative, being given, two other axes, or fixed lines, may be found, such that calling* θ *and* θ' *the angles made with them respectively by a ray traversing a spherical portion of the medium, the tint polarized shall be proportional to* $\sin \theta . \sin \theta'$.*

Resultant axes arising from the joint action of two rectangular polarizing axes. Fig. 199. Let A C and B C (fig. 199) be the two polarizing axes including a right angle, of which let B C be the more powerful. Let O C be a ray penetrating the crystal in that direction; and in a plane P C Q perpendicular to A C B, draw any two lines P C, Q C, making equal angles with B C, either of which we will represent by x. Then if a sphere about C as a centre be conceived, it will intersect the planes A C B, P C Q, O C A, O C B, O C P, O C Q in lines of great circles B A, P B Q, O A, O B, O P, O Q, and we shall have $PB = QB = x$, $OA = \alpha$, $OB = \beta$, $OP = \theta$, $OQ = \theta'$; and by Spherical Trigonometry, from the triangle O B P, we have

$$\cos OBP \left(= \sin OBA = \sin AOB . \frac{\sin OA}{\sin AB} = \sin \alpha . \sin C, \text{ since } AB = 90° \right)$$

$$= \frac{\cos \beta . \cos x - \cos \theta}{\sin \beta . \sin x}.$$

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* M. Biot appears to have first noticed the fact announced in this proposition, *viz.* that Dr. Brewster's hypothesis of polarizing axes leads to a result *mathematically* identical with his own elegant law of the product of the sines. He has, however, suppressed his demonstration. Dr. Brewster's verification of this coincidence of results seems to have been founded on a numerical comparison of Biot's experiments on sulphate of lime with his own theory.

and therefore $$-\cos\theta = \sin\alpha \,.\, \sin\beta \,.\, \sin x \,.\, \sin C - \cos\beta \,.\, \cos x,$$
and similarly from the triangle O B Q, since O B Q = 90° + O B A, we obtain a second relation
$$+\cos\theta' = \sin\alpha \,.\, \sin\beta \,.\, \sin x \,.\, \sin C + \cos\beta \,.\, \cos x\,;$$
and, adding and subtracting, (putting, for brevity's sake, $\cos\theta' = p$, $\cos\theta = q$,)
$$p + q = 2 \,.\, \cos\beta \,.\, \cos x\,; \qquad p - q = 2 \,.\, \sin\alpha \,.\, \sin\beta \,.\, \sin x \,.\, \sin C.$$
These equations express the geometrical relations subsisting between the lines P C, Q C, and the axes A C, B C; and, if combined with the equations of Art. 1028 and 1029, suffice to eliminate α, β, and C, and to express T in terms of x, θ, and θ' alone. To execute this, we have by the equations just demonstrated
$$\left(\frac{p+q}{2 \,.\, \cos x}\right)^2 = \cos\beta^2; \qquad \left(\frac{p-q}{2 \,.\, \sin x}\right)^2 = \sin\alpha^2 \,.\, \sin\beta^2 \,.\, \sin C^2;$$
and in the latter, putting $1 - \cos C^2$ for $\sin C^2$, and for $\cos C^2$ its value given by Art. 1028, which, since $\gamma = 90°$, becomes simply
$$\sin\alpha^2 \,.\, \sin\beta^2 \,.\, \cos C^2 = \cos\alpha^2 \,.\, \cos\beta^2,$$
we have
$$\left(\frac{p-q}{2 \,.\, \sin x}\right)^2 = \sin\alpha^2 \,.\, \sin\beta^2 - \cos\alpha^2 \,.\, \cos\beta^2,$$
$$= \sin\alpha^2 - \cos\beta^2.$$
Hence we get, for the values of $\sin\alpha^2$ and $\sin\beta^2$,
$$\sin\alpha^2 = \left(\frac{p+q}{2 \,.\, \cos x}\right)^2 + \left(\frac{p-q}{2 \,.\, \sin x}\right)^2,$$
$$\sin\beta^2 = 1 - \left(\frac{p+q}{2 \,.\, \cos x}\right)^2;$$
and, substituting these in the equation of Art. 1029,
$$T^2 = \left\{b + \frac{a-b}{4 \,.\, \cos x^2}(p+q)^2 + \frac{a}{4 \,.\, \sin x^2}(p-q)^2\right\}^2 - \frac{a\,b}{\sin x^2}(p-q)^2.$$
Such is the general form of the expression for the tint, when referred to arbitrary axes in the manner here supposed, and it is complicated enough; but if we fix the position of the new axes so as to make $\sin x^2 = \frac{a}{b}$ the complication disappears; we have then $\frac{a}{4 \,.\, \sin x^2} = \frac{b}{4}$, and $\frac{a-b}{4 \,.\, \cos x^2} = \frac{b}{4}$, so that the value of T^2 reduces itself to
$$T^2 = b^2\left\{\left(1 - \left(\frac{p+q}{2}\right)^2 + \left(\frac{p-q}{2}\right)^2\right)^2 - (p-q)^2\right\},$$
$$= b^2\{(1-p\,q)^2 - (p-q)^2\} = b^2\{1 - p^2 - q^2 + p^2 q^2\},$$
$$= b^2(1-p^2)(1-q^2) = b^2 \,.\, \sin\theta^2 \,.\, \sin\theta'^2,$$
restoring the values of p and q, or $\cos\theta'$ and $\cos\theta$, consequently
$$T = -b \,.\, \sin\theta \,.\, \sin\theta'.$$
The negative sign is prefixed for the reason stated further on in Art. 1034.

Thus we see that the combined action of the two axes in the manner here supposed, on Dr. Brewster's principles, will give rise to a series of isochromatic lines arranged in the form of sphero-lemniscates about two poles P, Q, determined by the condition 103
$$\sin B P = \sin B Q = \sqrt{\frac{\text{intensity of the feebler axis}}{\text{intensity of the stronger}}}\,;$$
and the lines C P, C Q so determined have therefore the character of the optic axes in biaxal crystals, and may be designated with Dr. Brewster by the name of resultant axes. We must be careful, however, not to confound a *resultant* with a *polarizing* axis in this theory.

1032. Combination of a positive with a negative axis.

If the polarizing axes be not of the same denomination, as if one be positive and the other negative, the value of sin B P becomes imaginary, and the tints cannot be so arranged. But if we suppose the new axes to lie in this case in the *same* plane with the polarizing ones, as in fig. 200, all other things remaining, we have here
$$\cos O B A = +\cos O B Q, \qquad \text{and } \cos O B A = -\cos O B P,$$
but $$\cos O B A = -\frac{\cos\alpha}{\sin\beta}, \qquad \text{and } \cos O B Q = \frac{\cos\beta \,.\, \cos x - \cos\theta'}{\sin\beta \,.\, \sin x},$$
so that we find $$\cos\theta' = p = \cos\beta \,.\, \cos x + \cos\alpha \,.\, \sin x\,;$$

and similarly $\cos \theta = q = \cos \beta \,.\, \cos x - \cos a \,.\, \sin x,$

whence, by adding and subtracting, we get at once

$$\cos a = \frac{p - q}{2 \,.\, \sin x}; \qquad \cos \beta = \frac{p + q}{2 \,.\, \cos x},$$

which, substituted in the value of T^2, give

$$T^2 = \left\{(a + b) - \left(\frac{a}{\sin x^2} + \frac{b}{\cos x^2}\right)\frac{p^2 + q^2}{4} + \left(\frac{a}{\sin x^2} - \frac{b}{\cos x^2}\right)\frac{p\,q}{2}\right\}^2$$

$$- 4\,a\,b + \frac{a\,b}{\sin x^2 \,.\, \cos x^2}\,(p^2 + q^2) + \frac{2\,a\,b\,(\sin x^2 - \cos x^2)}{\sin x^2 \,.\, \cos x^2}\,p\,q.$$

Now, if in this we suppose $\frac{a}{\sin x^2} + \frac{b}{\cos x^2} = 0$, or $\tan x^2 = -\frac{a}{b}$, it will, on substitution and reduction, take the form

$$T^2 = \frac{(1 - p^2)\,(1 - q^2)}{\cos x^4} \,.\, b^2 = \frac{b^2 \,.\, \sin \theta^2 \,.\, \sin \theta'^2}{\cos x^4}$$

and $$T = \frac{-\,b}{\cos x^2} \,.\, \sin \theta \,.\, \sin \theta';$$

that is, restoring the value of x, $\left(\text{since } \tan x^2 = -\frac{a}{b}, \text{ and therefore } \cos x^2 = \frac{b}{b - a}\right)$, finally,

$$T = -\,(b - a) \,.\, \sin \theta \,.\, \sin \theta'.$$

1033. Position of resultant axes in this case. Thus, in this case also, the isochromatic lines are sphero-lemniscates, and the only difference is that the poles lie now in the plane of the polarizing axes, instead of at right angles to it; and that whereas in the former case the semi-angle between them (x) was given by the equation $\sin x = \sqrt{\frac{a}{b}}$, that is, $\cos x = \sqrt{\frac{b - a}{b}}$, in this it is given by the equation $\cos x = \sqrt{\frac{b}{b - a}}$.

1034. Cases of the resolution of a single axis into two. *Corol.* 1. In the case when $a = b$, or when the two polarizing axes are of the same denomination and of equal intensity, we have $\sin x = 1$, or $x = 90°$, so that the angle between the resultant axes being 180°, they form one straight line, the lemniscates become circles, and the single *resultant* axis has now the characters of a *polarizing* axis. Hence, *vice versâ*, a single polarizing axis, in any direction, may be resolved into two others equal in intensity, at right angles to it and to each other, and of an opposite denomination to the resolved axis. This follows from the negative sign of T, which is prefixed in extracting the square root in Art. 1030 and 103[illegible]; because in the case supposed, when the arc A B is 90° the angle C or A O B is necessarily greater than 90°, and 2 C the angle of the parallelogram of tints > 180°; so that the diagonal will be to be measured backwards through the angle, or must be a negative quantity.

1035. Composition of three equal rectangular axes. *Corol.* 2. Since a single axis is equivalent to two equally intense axes of an opposite character at right angles to it and to each other, if we superadd to both another equal axis also of the opposite kind, and in the direction of the first, this will destroy the effect of the first, and therefore the combination of three equal and similar axes arising on the other side at right angles to each other, will be equivalent to none at all. Thus, three equal rectangular axes of the same character destroy each other's effects. This is Dr. Brewster's account of the want of polarization and double refraction in crystals whose primitive form is the cube, regular octohedron, &c., and whose secondary forms indicate a perfect symmetry in their molecules with respect to three rectangular axes.

1036. There is no necessity to pursue further the general subjects of this species of composition of axes and of tints. Indeed, it appears to us that the rule for the parallelogram of tints, as laid down by Dr. Brewster, becomes inapplicable when a third axis is introduced; for this obvious reason, that when we would combine the compound tint arising from two of the axes (A, B) with that arising from the action of the third (C,) although the *sides* of the new parallelogram which must be constructed are given, (*viz.* the compound tint T, and the simple tint t'',) yet the wording of the rule leaves us completely at a loss what to consider as its *angle*, inasmuch as it assigns no single line which can be combined with the axis C in the manner there required, or which *quoad hoc* is to be taken as a resultant of the axes A, B. For further information therefore on this subject we shall content ourselves with referring the reader to his original Paper in the *Transactions of the Royal Society*, 1818.

§ X. *Of Circular Polarization.*

1037. The first phenomena referable to the class of facts to whose consideration this section will be devoted, were noticed by M. Arago in his Memoir published among those of the Institute for 1811 on the colours of crystallized plates. He observed that when a polarized ray was made to traverse at right angles a plate of rock crystal

1041. Right and left handed quartz. In the course of these researches M. Biot was led to the very singular discovery of a constant difference subsisting in different specimens of rock crystal, in the *direction* in which this rotation or angular shifting of the plane of polarization of a ray traversing them takes place. In some specimens it is observed to be from right to left, in others from left to right. To conceive this distinction, let the reader take a common cork-screw, and, holding it *with the head towards him*, let him turn it in the usual manner, as if to penetrate a cork. The head will then turn the same way with the plane of polarization of a ray in its progress *from* the spectator through a *right-handed* crystal may be conceived to do. If the thread of the cork-screw were reversed, or what is termed a *left-handed thread*, then the motion of the head as the instrument advanced would represent that of the plane of polarization in a left-handed specimen of rock crystal. It will be observed, that we do not here mean to say that the plane of polarization *does* so revolve in the interior of a crystal, but that the ray at its egress presents the same phenomena as to polarization *as if* it had done so. This is necessary, for we shall see presently that a very different view of the subject may be taken.

1042. Phenomena of plagiedral crystals. In crystals which present this remarkable difference, when cut and polished, and when the external indications of crystalline form are obliterated, no other difference can be detected. Their hardness, transparency, refractive and double refractive powers are the same; and, with the exception of the direction in which it takes place, their effects in deviating the planes of polarization of the rays which traverse them are alike. Experiments subsequent to M. Biot's researches have, however, established, as a result of extensive induction, a very curious connection between this direction and the crystalline forms affected by individual specimens. In the variety of crystallized quartz, termed by Haüy, *Plagiedral*, there occur faces which (unlike those in all the more common varieties) are unsymmetrically related to the axes and apices of the primitive form, whether regarded as the rhomboid or bipyramidal dodecahedron. Fig. 201 represents such a crystal, in which when the apex A is set upwards, the faces C, C, C, are observed to lean all in one direction, *viz.* to the right, with respect to the axis, as if distorted from a symmetrical position by some cause acting from left to right all round the crystal. When the vertex B is set upwards, the same distortion, and in the same direction, is observed in the plagiedral faces D, D, D, and crystals of quartz are excessively rare, if they exist at all, in which two plagiedral faces leaning opposite ways occur. Now it has been ascertained, that in crystals where one or more of these faces, however minute and even of microscopic dimensions, can be seen, we may thence predict with certainty the direction of rotation in a plate cut from it, which is always that in which the plagiedral face appears to lean with respect to an observer regarding it as the reader does the figure, which represents a *right-handed* crystal. *Hence we are entitled to conclude, that whatever be the cause which determines the direction of rotation, the same has acted in determining the direction of the plagiedral faces.* Other crystallized minerals, as apatite, &c. also present plagiedral and unsymmetrical faces; but, independent of their extreme rarity, they are not possessed of the property of rotation; so that at present we are unable to say whether this curious law be general, or to conjecture to what principles it will hereafter prove to be referable.

1043. Superposition of plates of rock crystal. When two plates of rock crystal are superposed, if they be both right-handed or both left, their joint rotatory effect will be the sum of their respective ones, *i. e.* each ray's plane of polarization will be shifted through an angle equal to the sum of those through which it would have been shifted by their separate actions. If their characters be opposite, it will be their difference, *i. e.* the *index of rotation* in a right-handed crystal being regarded as positive, it will be negative in a left-handed one.

1044. Amethyst. The amethyst (and, possibly, also the agate in some cases) presents the very remarkable and curious phenomenon of these two species of quartz crystallized together in alternate layers of very minute thickness. Accordingly, when a crystal of amethyst is cut at right angles to the axis, and examined by polarized light transmitted exactly along the axis, and analyzed as usual, it offers a striped or fringed appearance, as represented in fig. 202, variegated with different colours, according to the different planes of polarization assumed by the rays emergent at its several points, and presenting, according to the distribution of its elements, the most beautiful combinations and contrasts of coloured fasciæ and spaces. For a particular account of these phenomena, the reader is referred to a Paper by Dr. Brewster, (*Edinburgh Transactions*, vol. xi.) who first observed and publicly described them, though we have reason to believe them to have been known to others by independent observation previous to the publication of his very curious and interesting Memoir. The layers may be distinctly seen *cropping out* to the surface in a fresh fracture of the mineral, and imparting that peculiar undulated fracture which is the chief mineralogical character of this substance by which it is known from ordinary quartz.

1045. Rotatory phenomena in liquids. But the phenomena of rotation as above described are not confined to quartz. Many liquids, and even vapours exhibit it, a circumstance which would seem very unexpected, when we consider that in liquids and gases the molecules must be supposed unrelated to each other by any crystalline arrangement, and independent of each other; so that to produce any such phenomena, each individual molecule must be conceived as unsymmetrically constituted, *i. e.* as having a right and a left side. M. Biot and Dr. Seebeck appear about the same time to have made this singular and interesting discovery; but the former has analyzed the phenomena with particular care, and it is from his Memoir above cited that we extract the following statements. The liquids in which he observed a right-handed rotatory property, according to our sense of the word above explained, in which the observer is supposed to look in the direction of the ray's motion, are oil of turpentine, oil of laurel, vapour of turpentine oil, and an alcoholic solution of artificial camphor produced by the action of muriatic acid on oil of turpentine. The left-handed rotation was observed by him in oil of lemons, syrup of cane sugar, and alcoholic solution of natural camphor. In all these, the intensity of the action, or the velocity of rotation, was much inferior to quartz. The following are their *indices of rotation*, or the arcs of rotation produced by one millimètre of thickness in the plane of polarization of a certain homogeneous red ray chosen by M. Biot for a standard, as calculated from his data.

be *most* refracted *downwards;* and thus the separation of the images will be doubled, and the same will take place at the common face C B. Thus this combination, both from the doubling of the separation, and the greatness of the angles of incidence, is peculiarly well adapted to render sensible any bifurcation, or difference of velocities, however small, which may exist along the axis. Accordingly, with the compound prism, so constructed, a double refraction is produced; and the two rays are really observed to emerge, making a sensible angle with each other.

1049. Characters of circular polarization. But it is, moreover, observed, that though thus separated by a real double refraction, the two pencils have not acquired the characters which double refraction usually impresses on the ordinary and extraordinary rays, at their emergence, but very different ones. In common cases of double refraction the two emergent pencils are each wholly polarized in opposite planes, and either of them when examined with a doubly refracting prism gives two unequal images, one alternately more and less bright than the other, as the prism revolves through successive quadrants. This is not the case with the two pencils produced in the case before us, for

First, Either of them, when examined with a doubly refracting prism, gives constantly two images of equal intensity, in whatever plane the principal section of the latter be placed. In this respect, then, they present the characters of unpolarized light, and may be regarded as each consisting of two rays polarized at right angles to each other. But

1050. Other characters of circularly polarized rays. Secondly, They differ from ordinary, or unpolarized light, in a very remarkable property, which was first discovered by Fresnel, and is a chief distinctive character of this kind of polarization. Suppose either of them to be incident at right angles on the surface A B of a parallelepiped of crown glass of the refractive index 1.51 having its angles A B C and A D C each 54½°, it will then be totally reflected at the internal surface B C; and (if the parallelepiped be long enough) again in the same plane at the opposite surface A D, and will emerge at length perpendicularly through the surface B C. But the emergent ray, instead of comporting itself as ordinary light, will now be found to be *completely polarized* in a plane 45° inclined to that in which the reflections were made, whatever may have been the position of that plane. If both the pencils be treated in this manner, it will be found that the one, after its two total reflexions will assume a plane of polarization 45° in azimuth to the *right*, and the other 45° to the *left* of the plane of the reflexions.

Thus we see that the effect of double refraction along the axis of quartz is to impress on either of the emergent pencils opposite polarizations, or modifications, of a nature totally distinct from that given to a ray by ordinary reflexion, or by double refraction through Iceland spar, &c.; and, as in the last described experiment, so long as the ray enters perpendicularly into the first surface of the glass parallelepiped, it is indifferent in what plane the two reflexions are operated, and since when presented to a doubly refracting prism in any plane indifferently it always divides itself into two equal pencils, it is evident that the ray thus modified has *no sides, i. e.* no particular relations to certain regions of space; and therefore that the epithet *circular polarization*, apart from all theoretical considerations, may be naturally applied to this peculiar modification. But the characters above described are not the only ones belonging to a ray thus modified, for

Thirdly, Such a ray being transmitted through a thin crystallized lamina, and parallel to its axis, is divided by subsequent double refraction into two rays of complementary colours, thus marking a decided difference between it and a ray of common light; while, on the other hand, these colours are not the same with those which would arise from a ray of light polarized in the usual way and similarly analyzed, but differ from them by an exact quarter of a tint, either in excess or defect, as the case may be.

1051. Fourthly, A ray so modified by this peculiar double refraction, when transmitted again along the axis of rock crystal, or through columns of oil of turpentine, of lemons, &c., and then analyzed by a double refracting prism, gives rise to no phenomena of colour, differing in this from polarized, and agreeing with common light.

1052. Another mode of producing circular polarization. Another independent mode of impressing on a ray all this assemblage of characters has been discovered by M. Fresnel. It consists in inverting the process described in Art. 1049. Thus, into the side C D of the glass parallelepiped there mentioned, let a common polarized ray be introduced at a perpendicular incidence, the parallelepiped being so placed that the plane of internal reflexion at the side A D shall be 45° inclined to that of its primitive polarization. Then, after undergoing two total internal reflexions at G and F, it will emerge at E deprived of its characters of ordinary polarization and endowed with those of circular, and being no way distinguishable from one of the pencils produced by double refraction along the axis of rock crystal.

1053. It remains to show, however, that the characters here described, as impressed on a ray by transmission along the axis of rock crystal, are really those which ought to belong to a ray propagated by circular vibrations. And, first, it follows from Art. 627, that this latter ray is the resultant of two rays polarized at right angles, and differing in their phases by a quarter undulation. It must, therefore, of necessity possess the first character, viz. that of division into two equal pencils by double refraction in any plane, for the same reason that unpolarized light is so divided, the difference of phases having nothing to do with this character.

1054. In the next place, a ray propagated by circular vibrations when incident on rock crystal in the direction of the axis, will (by hypothesis) be propagated along it by that elasticity which is due to the direction of its rotation, the wave then will enter the crystal without further subdivision, and there will be no difference of paths, or interfering rays at its emergence; and, of course, no colours produced on analyzing by double refraction, which is another of the characters in question.

1055. Tints produced by circularly polarized When a ray propagated by circular vibrations is incident on a crystallized lamina it may be regarded as composed of two, one polarized in the plane of the principal section, the other at right angles to it, of equal intensity, and differing in phase by a quarter undulation. Each of these will be transmitted unaltered, and therefore at their emergence and subsequent analysis will comport themselves in respect of their interference just as would do the two portions of a ray primitively polarized in azimuth 45°, and divided into two by

Light.

Fig. 205. the direction A P, the other in a circle equal and similar to B Q, and in the direction B Q, fig. 205. Let A, B be two molecules setting out at once from A, B in these circles with equal velocities, then will the motion of C at any instant be equal to that compounded of the motions of A and B at that instant. When A comes to P let B come to Q, then arc $A P = B Q$, and the motions at P and Q will be each resolved into two, those of which parallel to C D (a perpendicular to P Q) conspire, while those in the directions P D and Q D parallel to P Q oppose, and being equal destroy each other; thus C will move only in virtue of the sum of the two former, and its vibrations will therefore be rectilinear, and in the plane C D perpendicular to P D Q. If the thickness of the plate of quartz were nothing, or such that the interval of retardation were an exact number of undulations, A, B would lie at opposite extremities of a diameter, and C D the new plane of polarization would be perpendicular to A M that diameter, or coincident with the plane of primitive polarization. But if not, the quicker motion will have gained on the other a part of a circumference M B, which is to a whole circumference as the thickness of the plate is to that which would produce a difference of a whole undulation; and at the emergence of the two waves into air, after which they circulate with equal velocity, if we suppose the one molecule to be setting out from A, the other will be setting out, not from M the opposite extremity of the diameter, but from B, and therefore C D the new plane of polarization (which from what has just been shown must always bisect the angle A C B) will no longer be coincident with C N the primitive plane of polarization, at right angles to A M, but will make an angle D C N with it equal to half B C M, and therefore proportional to M B, or to the interval of retardation, *i. e.* to the thickness of the plate. Thus the system of rays emerging from the rock crystal plate will compound one ray polarized in one plane, and in the position the original plane would have had, had it revolved uniformly round the ray as an axis during its passage through the plate. Thus we have a complete and satisfactory explanation of the apparent rotation of the plane of polarization, as observed by Biot in the case of a homogeneous ray.

1058. It is observed, that the spectra formed by the double refraction of rock crystal along its axis are very highly and unequally coloured. The violet rays are most *separated*, and therefore the difference of velocities of the two rotating pencils is much greater for violet than for red rays. Consequently, the apparent velocity of rotation of the plane of polarization will also be greater for the violet rays in the same proportion, and thus arise all the phenomena of coloration observed and described by M. Biot. It is scarcely possible to imagine an analysis of a natural phenomenon more complete, satisfactory, and elegant. With regard to the physical reason of the difference of velocity in the two circular polarized pencils within the quartz, it is true we remain in the dark; but the fact of such difference existing is now shown to be no hypothesis, but a fact demonstrated by their observed difference of refraction, and by the observed characters of the two emergent rays.

§ XI. *Of the Absorption of Light by Crystallized Media.*

1059. Absorption of polarized light by double refracting crystals.

Crystallized media, endowed with the property of double refraction, are found to absorb the differently coloured rays differently, according to their planes of polarization, and the manner in which these planes are presented to the axis of the crystal, and also to exert very different absolute absorbing energies on rays of one colour polarized in different planes. A remarkable instance of this has been already often referred to in the case of the brown tourmaline, a plate of which, cut parallel to the axis, absorbs almost entirely *all* rays polarized in the plane of the principal section, and lets pass only such among oppositely polarized rays as go to constitute a brown colour.

1060. Property of the tourmaline

When such a plate, then, is exposed to natural light, since at the entrance of each ray into its substance it is resolved into two, one polarized in the plane of the principal section, and one perpendicular to it, the former is absorbed in its progress by the action of the crystal, while the brown portion of the latter escaping absorption, but retaining at its egress the polarization impressed on it, after traversing the plate, appears with its proper colour, and *wholly polarized in a plane at right angles to the axis.* Thus the curious phenomenon of the polarization of light by transmission through a plate of tourmaline, or other coloured crystal, is explained, or at least resolved into the more general fact of an absorbing energy varying with the internal position of the plane of polarization. The crystal, in virtue of its double refractive property, divides the ray into two, and polarizes them oppositely; and the unequal absorption of these two portions *subsequently* causes the total suppression of one, and the partial of the other of the portions so separated. Thus we see that the polarized beam obtained by transmission through a tourmaline must always be of much less than half the intensity of the incident light.

Explained.

1061. Gradual destruction of the ordinary ray.

The destruction of the pencil polarized in the principal section is not, however, sudden; for if the plate of tourmaline be very thin, the emerging pencil will only be partially polarized, indicating the existence in it of rays belonging to the other pencil. This is best shown by cutting a tourmaline into a prism having its refracting edge parallel to the axis, and its angle small, so as to produce a wedge whose thickness increases not too rapidly. If we look through this at a distant candle, we shall see only one image, *viz.* the extraordinary through the back of the wedge, (if thick enough;) but as the eye approaches the edge, the ordinary image appears at first very faint, but increasing in intensity till, at the very edge, it becomes equal to the other. At the same time the colour of the latter, which at first was intense, becomes diluted; and the images approximate not only to equality of light, but to similarity of tint. We see by this, too, that in strictness the ordinary pencil is never *completely* absorbed by any thickness, however great; but as it diminishes in geometrical progression as the thickness increases in arithmetical, the absorption may for all practical purposes be regarded as total at moderate thicknesses

1062. Media possess two distinct absorbing powers.

The indefatigable scrutiny of Dr. Brewster, to whom we owe nearly all our knowledge on this subject, has shown that the same property is possessed in greater or less perfection by the greater number of coloured doubly refracting media; and the expression of the property may be rendered general by considering all doubly refractive media as possessing two distinct absorbing powers or two separate *scales of absorption* for the two pencils, or (adopting the language of § III. part 2) as having two distinct *types*, or curves expressing the law of absorption throughout the spectrum. If these types be both straight lines parallel to the abscissa, the crystal will be colourless. Such are limpid carbonate of lime, quartz, nitre, &c. If they be similar and equal curves, the medium, although coloured, will present the same colour, and the same intensity of tint, in common as in polarized light. If dissimilar, or if, although similar, their ordinates are in a ratio of inequality, the character, in the former case, and the intensity in the latter, will vary on a variation of the plane of polarization of the incident beam, so that if a plate cut from such a crystal be exposed to a beam of polarized white light, and turned round in its own plane, or otherwise inclined to the beam, its colour will change either in hue or depth or both. Dr. Brewster has remarked such change of colour and the phenomena connected with it in a great variety of crystals both with one and two axes, of which he has given a list in a most interesting Paper on the the subject in the *Philosophical Transactions*, 1819, p. 1, which we strongly recommend to the reader's perusal. It may be familiarly seen in a prism of smoked quartz of a pretty deep tinge, which held with its axis in the plane of polarization appears of a purple or amethyst colour, while if held in a direction at right angles to this position, its colour is a yellow brown.

1063. Absorption of the rays in the two pencils examined in crystals with one axis.

But in order to analyze the phenomena more exactly, we must examine the two pencils separately. To this end Dr. Brewster took a rhomboid of yellow carbonate of lime of sufficient thickness to give two distinct images of a small circular aperture placed close before it, and illuminated with white light, when he observed that the image seen by extraordinary refraction appeared of a deeper colour and less luminous than the other, being an orange yellow, while the ordinary image was a yellowish white. He found, moreover, that the difference of colour was greater as the paths of the refracted rays within the crystal were more inclined to the axis, being 0 when the rays passed along the axis, and a maximum when at right angles to it. If we denote by Y_o and Y_e the ordinates of the curves, expressing the law of absorption as in Art. 490, for the ordinary and extraordinary pencil respectively, these will both therefore decrease as we proceed from the red to the violet end of the spectrum, corresponding to types of the character of that represented in fig. 114; but Y_e being smaller, and decreasing more rapidly than Y_o. Moreover, since $Y_o = Y_e$ in the axis, and since as we recede from the axis Y_o increases (because the colour of the ordinary pencil becomes whiter and more luminous) while Y_e diminishes by the same degrees, (the extraordinary becoming deeper and less bright,) we shall represent both these changes satisfactorily by putting

Formulæ for the light transmitted in each.

$$Y_o = Y\,(1 + k\,.\,\sin\theta^2)\,; \qquad Y_e = Y\,(1 - k\,.\,\sin\theta^2).$$

These give $Y_o + Y_e = 2\,Y =$ constant, or independent of θ, which agrees with an observation of Dr. Brewster, that in every situation the combined tints of the two images are exactly the same with the natural colour of the mineral, (which, in this instance, appears to have been alike in all directions.)

1064. Cases of two distinct colours.

In this case, then, the colour of a plate of the crystal of given thickness exposed to natural light will be the same, whether the plate be cut parallel or perpendicular to the axis. But Dr. Brewster has observed, that this is not always the case, but that great differences occasionally exist in this respect. Thus he found, that in some specimens of *sapphire* the colour when viewed *along* the axis was deep blue, and when *across* it yellowish green. In Idocrase an orange-yellow tint is seen along the axis, and a yellowish green across it. Specimens of tourmaline also are not uncommon in which the tint across the axis is green, while along the axis it is deep red; and, in general, this mineral is always much more opaque in the direction of the axis than in any other; so much so, indeed, that plates of a very moderate thickness cut across the axis are nearly impermeable to light. One of the most remarkable instances of this kind we have met with is a variety of sub-oxysulphate of iron, which crystallizes in regular hexagonal prisms, and which viewed through two opposite sides of the prism is light green, but along the axis, a deep blood red, so intense that a thickness of $\frac{1}{20}$ inch allows scarcely any light to pass. It is obvious, that to such cases the formulæ of the last article do not extend. But a slight modification will enable us to embrace the phenomena in an analytical expression. For if we take

Investigation of formulæ for these cases.

$$y_o = X_o + Y_o\,.\,\sin\theta^2\,; \qquad y_e = X_e + Y_e\,.\,\sin\theta^2\,;$$

where X_o, Y_o, &c. as well as y_o, y_e represent functions of λ (the length of an undulation) being the ordinates of so many curves, or types of tints, whose relations are to be determined, we have

$$y_o + y_e = (X_o + X_e) + (Y_o + Y_e)\,\sin\theta^2.$$

Now this is the tint which a sphere of the medium of a diameter $= 1$ will exhibit when viewed by natural light along a diameter inclined θ° to the axis. If we represent by A and B the ordinates of the types of the tints it is observed to exhibit in the directions of the axis, and perpendicular to it, we have, when $\theta = 0$,

$$y_o + y_e = A = X_o + X_e\,;$$

and when $\theta = 90^\circ$,

$$y_o + y_e = B = (X_o + X_e) + (Y_o + Y_e),$$

whence we have

$$Y_o + Y_e = B - A\,;$$

Expression of the colour transmitted in common light.

and the tint exhibited by ordinary light at the inclination θ to the axis, will be represented by

$$y_o + y_e = A + (B - A)\,.\,\sin\theta^2,$$

$$= A\,.\,\cos\theta^2 + B\,.\,\sin\theta^2.$$

Thus in the case of our sub-oxysulphate of iron, A is the ordinate of the type of a deep blood-red tint, and B in like manner represents a bright pale green, so that we shall have at any intermediate inclination θ

$$\text{tint} = (\text{deep red}) \times \cos\theta^2 + (\text{light green}) \times \sin\theta^2,$$

which represents faithfully enough the gradual passage of one hue into the other as the inclination changes.

1065. When illuminated by polarized light.

Suppose now the incident beam polarized in any plane, and let the plane in which the ray and the axis of the sphere lie make an angle $= \alpha$ with that plane. Then would $\cos\alpha^2$ and $\sin\alpha^2$ represent the intensities of the ordinary and extraordinary pencils which superposed make up the emergent beam, were the crystal limpid; but in virtue of its absorbent powers, they will be reduced respectively to

$$y_o = \cos\alpha^2 (X_o + Y_o \sin\theta^2), \quad \text{and } y_e = \sin\alpha^2 (X_e + Y_e \,.\, \sin\theta^2),$$

so that at their emergence they will no longer make up white light, but a variable tint whose type has for its ordinate

$$(X_o \,.\, \cos\alpha^2 + X_e \,.\, \sin\alpha^2) + (Y_o \,.\, \cos\alpha^2 + Y_e \,.\, \sin\alpha^2) \,.\, \sin\theta^2,$$

in which it will be recollected that $X_o + X_e = A$, and $Y_o + Y_e = B - A$.

To determine the individual values of X_o, &c. however, we must have two more conditions, and these will be found by considering, first, that in the direction of the axis the tint must be independent of α, which gives $X_o \,.\, \cos\alpha^2 + X_e \,.\, \sin\alpha^2$ independent of α, and therefore $X_o = X_e$, and either of them $= A$. To get another condition, let the tints be noticed which the sphere or crystal exhibits when its axis is perpendicular to the visual ray; and, first, coincident with, next, perpendicular to, the plane of polarization, *i. e.* when $\alpha = 0$, and $\alpha = 90°$. These are respectively $X_o + Y_o$, and $X_e + Y_e$; and calling these a and b, we have

$$Y_o = a - X_o = a - A, \quad Y_e = b - A.$$

Hence the final expression for the tint seen in polarized light will be

$$A + \{ (a - A) \,.\, \cos\alpha^2 + (b - A) \sin\alpha^2 \} \,.\, \sin\theta^2,$$

that is,

$$A \,.\, \cos\theta^2 + \{ a \,.\, \cos\alpha^2 + b \,.\, \sin\alpha^2 \} \,.\, \sin\theta^2,$$

in which it will be observed that a and b are complements of each other to the tint B, because

$$a + b = X_o + Y_o + X_e + Y_e = B, \text{ by Art. 1064.}$$

1066. Dichroism.

Such is the expression for the apparent hue of crystals with one axis, which exhibit a variable colour in common or polarized light, according to their position with respect to the incident light. The phenomenon in question may be generally termed *dichroism*, though the word has usually been applied only to that particular case where a marked change in the character of the tint takes place, as from red to green, &c.

1067. Dichroism in biaxal crystals. Fig. 206. Colours of iolite. Phenomena of epidote.

The dichroism of biaxal crystals differs in many of its phenomena from those having only one optic axis. If we look through a plate, or into a crystal of any biaxal mineral, having the property in question, illuminated by natural light in such a direction that the visual ray within the crystal shall pass along, and in the immediate neighbourhood of, one of the axes, we shall perceive a phenomenon like that represented in fig. 206, consisting of two similar and equal sombre spaces A B one on either side of the pole P, and of the principal section P P′, and if we look along the other axis P′ a similar pair of spaces will be seen in its neighbourhood. In the mineral called *dichroite* by Hauy, (on account of the striking difference of its colours in different positions,) or *iolite* (from its violet hue) by others,* of which the phenomena have been described by Dr. Brewster in the Paper already cited, these spaces are of a full blue colour, while the intermediate region towards O, along the line O P C, and the space beyond P towards C are yellowish white. In epidote the sombre spaces are *brown*, and the region around O and in the principal section green, of a greater or less degree of dilution. In this latter mineral (at least in some of its more ordinary varieties of crystalline form, *viz*. in long striated prisms much flattened, and terminated by dihedral summits placed obliquely, so as to truncate two of the angles of the prism) the phenomena are seen without any artificial section, merely by looking in obliquely, across the axis of the prism; and the same is true of many other minerals, as, for instance, the axinite, in which the transition of colour is extremely remarkable and beautiful.

1068. Connection of the phenomena with the polarized rings and optic axes Fig. 207.

The phenomena of dichroism in biaxal, as well as in uniaxal crystals, are evidently related to the optic axes, and depend on the planes of polarization assumed by the intromitted light, during its transit through the crystal to whose absorptive power it is subjected. Now, if we consider the form and situation of the sombre spaces where the greatest absorptive energy is exerted, we are at once struck by their analogy with those occupied by the more vividly coloured parts of the rays about the axes in the situation of fig. 179. That figure represents (Art. 900) the extraordinary set of rings as seen in a crystal whose principal section is in the plane of primitive polarization. Fig. 207 represents the ordinary or complementary set as seen around either of the axes, the pole P, and the principal section being here occupied with white light, and very bright, in consequence of its containing the whole incident light, while the lateral or coloured portions occupied by the rings are less illuminated, the colours originating in an abstraction of certain rays.

Conceive now a number of such sets of coloured rings not all of exactly the same dimensions, nor having

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* Mobs, with his usual contemptuous disregard of, or rather hostility to, all ordinary convenience and received usage, chooses to call this mineral "*prismatic quartz*." Such a nomenclature *must* ere long work out its own destruction, but while it subsists the nuisance is intolerable. We cannot but lament, that such a cause should exist to raise up prejudice against a system in many respects so useful and valuable.

A more symmetrical value of ϕ will, however, be had by expressing the value of $\sin 2\phi$, which being equal to $4 \,.\, \sin \phi^2 (1 - \sin \phi^2)$ is immediately given by substitution of the foregoing. If we execute the reductions we shall find that, putting S for $\frac{\theta + \theta' + 2a}{2}$ = half the sum of the sides of the triangle P A P′

$$\sin 2\phi = \frac{2(\theta + \theta')(\theta - \theta')}{(2a)^2} \,.\, \frac{\sqrt{S(S-\theta)(S-\theta')(S-2a)}}{\theta\theta'}.$$

Now $\frac{2\sqrt{S(S-\theta)(S-\theta')(S-2a)}}{\theta\theta'}$ is the well known expression for the sine of the angle P A P′ included between the sides θ, θ', and therefore calling this angle P, we have

$$\sin 2\phi = \frac{(\theta + \theta')(\theta - \theta')}{(2a)^2} \,.\, \sin P.$$

The nature of this expression renders the transition from plane to spherical triangles easy, and we may conclude consequently, that, in crystals where the axes make any angle $2a$, that if we take

$$\sin 2\phi = \frac{\sin(\theta + \theta') \,.\, \sin(\theta - \theta')}{(\sin 2a)^2} \,.\, \sin P,$$

and $\psi = a + \phi$, we shall still have the intensity of the extraordinary rings represented by $A(\sin 2\psi)^2$, and that of the ordinary by $1 - A + A \,.\, (\cos 2\psi)^2$, that is, $1 - A(\sin 2\psi)^2$, their sum being, as it ought, unity.

Form of the black cross in biaxal crystals investigated

1072. The black cross which divides the system of the primary rings, is too remarkable a feature not to require express notice. Its form, it is evident, must be determined by the condition that the line M A shall be everywhere perpendicular to C O D, in which circumstances the locus of A will be a curve marking out its central or blackest portion. The problem then is reduced to a purely geometrical one, Required a curve P A such that a line drawn from A bisecting the angle between lines A P, A P′ drawn to two given points P, P′, shall always be perpendicular to a given line C O D. To resolve this, retaining the former notation, and putting $OM = x$, $MA = y$, $OA = r$, we have

$$\cos AOP = \cos(AOM - a) = \frac{x \,.\, \cos a + y \,.\, \sin a}{r} = \frac{N}{r},$$

$$\sin AOP = \frac{y \,.\, \cos a - x \,.\, \sin a}{r} = \frac{M}{r},$$

putting N and M for the respective functions in the numerators of the fractions.

Now since PAM is half the angle PAP′, it is easy to see that we must have 2 × angle O′AM = PAO − P′AO.

But, $$\cos PAO = \frac{\theta^2 + r^2 - a^2}{2r\theta}; \quad \cos P'AO = \frac{\theta'^2 + r^2 - a^2}{2r\theta'};$$

and $$\sin PAO = \sin AOP \times \frac{PO}{PA} = \frac{aM}{r\theta}; \quad \sin P'AO = \frac{aM}{r\theta'};$$

consequentlv we have, first,

$$\sin 2OAM, \text{ or } \frac{2xy}{r^2} = \frac{aM}{2r^2}\left\{\frac{\theta'^2 + r^2 - a^2}{\theta\theta'} - \frac{\theta^2 + r^2 - a^2}{\theta\theta'}\right\} = \frac{aM}{2r^2\theta\theta'}(\theta'^2 - \theta^2), \qquad (a)$$

and, secondly,

$$\cos 2OAM = \frac{y^2 x^2}{r^2} = \frac{1}{r^2}\left\{\frac{(\theta^2 + r^2 - a^2)(\theta'^2 + r^2 - a^2)}{4} + a^2 M^2\right\}.$$

Now we have further,

$$\left.\begin{aligned} \theta^2 &= a^2 + r^2 - 2ar \,.\, \cos AOP = a^2 + r^2 - 2aN \\ \theta'^2 &= = a^2 + r^2 + 2aN \end{aligned}\right\}; \qquad \theta'^2 - \theta^2 = 4aN,$$

which substituted in the values of sin 2 O A M and cos 2 O A M above, give the equations

$$xy \,.\, \theta\theta' = a^2 \,.\, MN,$$
$$(y^2 - x^2) \,.\, \theta\theta' = r^4 + a^2(M^2 \quad N^2),$$

and, eliminating $\theta\theta'$ from these, we obtain

$$a^2(y^2 - x^2) \,.\, MN = xy\,\{r^4 + a^2(M^2 - N^2)\}.$$

In this it only remains to substitute for M and N their values $y \,.\, \cos a - x \,.\, \sin a$, and $y \,.\, \sin a + x \,.\, \cos a$, which done, the whole will be found divisible by r^4, and will reduce itself to the very simple equation

$$x\,y = a^2 . \sin a . \cos a = \frac{a^2}{2} . \sin 2\,a.$$

When the axes are near it is an hyperbola.

The black cross then is an hyperbola, passing through the poles **P, P′**, and having the planes of primitive polarization, and one perpendicular to it (C D and *c d*) for its asymptotes, and which as *a* approaches to 0, or 90°, approaches nearer and nearer to its asymptotes, with which it at last coincides in the limiting case, all which particulars are exactly conformable to fact, and may easily be verified by turning a plate of nitre round between crossed tourmalines. When the inclination of the axes is so considerable, that the rings about both poles cannot be seen at once, there will arise modifications from the substitutions of the sines, &c. of arcs for the arcs themselves, which it is not worth while to enter into.

1073. Empirical formula expressing the phenomena of dichroism

To return now to the phenomena of dichroism. That portion of the light transmitted by a biaxal coloured medium which has relation to the optic axes, and which forms the sombre brushes of colour (in fig. 206,) and the bright spaces which divide them, have evidently for their analytical expression a function of the form

$$\mathrm{Y} . (\cos 2\,\phi)^2 + \mathrm{B} . (\sin 2\,\phi)^2; \quad (a)$$

where Y and B are functions of λ, and represent the ordinates of the types of two fundamental tints, ϕ representing as before the angle PNA, fig. 208, or the angle made by the plane of ordinary polarization with the principal section. But besides this, the phenomena described by Dr. Brewster, as exhibited by the iolite, require us to admit two other portions, which may be more naturally referred, not to either of the optic axes but to the line C O (fig. 209) bisecting them, and having for its expression a function of the form $a . \cos \mathrm{O\,A}^2 + b . \sin \mathrm{O\,A}^2$. In this mineral, when exposed to common light (or to polarized, provided we place its principal section at right angles to that of polarization,) the lateral brushes A, B, fig. 206, are blue, and the bright rays which divide them, passing through the poles P, P′ are white, or yellowish white, and so far the phenomena agree with the expression (*a*) if we suppose Y to represent a bright yellowish white, and B a blue. But according to that expression alone, the blue spaces should be continued down to the equator C *a b* D, fig. 206, and there ought to be two directions C D and *a b* in which the mineral viewed transversely to the axis of the prism (which is perpendicular to the plane C *a b* D) should appear yellow, and two others, *m n* and *p q*, in which it should transmit a blue colour, while in the direction of the axis O it should appear yellow. Now, on the contrary, the equatorial colour is nearly uniform and pale yellow, while that along the axis O is blue; and in proceeding from the equator toward the axis O of the prism, the yellow diminishes, and the blue gains strength, whether we set out from C and D, or from *a* and *b*, precisely as would be indicated by the other formula

$$y . (\sin \mathrm{O\,A})^2 + b . (\cos \mathrm{O\,A})^2,$$

y representing a yellow white and *b* a blue tint. If, therefore, we put $\mathrm{O\,A} = \nu$, the joint expression

$$\mathrm{T} = (\mathrm{Y} . \cos 2\,\phi^2 + \mathrm{B} . \sin 2\,\phi^2) + (y . \sin \nu^2 + b . \cos \nu^2); \quad (b)$$

will be found to represent pretty correctly the variations of colour as far as they can be judged of by the eye. Thus, at O where $\nu = o$, and $\phi = 90°$, we have $\mathrm{T} = \mathrm{Y} + b$, which may indicate either a yellow, a white, or a blue, according as we suppose Y or *b* to be predominant. The fact being, that the tint at O is blue, we must suppose the latter to express the more decided colour. As we proceed from O along the sections O C, O D, or O *a*, O *b*, in both of which $\sin 2\,\phi = o$, we have

$$\mathrm{T} = (\mathrm{Y} + y . \sin \nu^2) + b . \cos \nu^2 = (\mathrm{Y} + b) + (y - b) . \sin \nu^2$$

Now *y* expressing a yellow white and *b* a strong blue, $y - b$ will express a proportionally vivid yellow, and therefore the blue tint $\mathrm{Y} + b$ seen along the axis will be diluted with more and more yellow as we approach the equator; at P P′, then, (by a proper assumption of numerical values) it will be rendered nearly neutral, after which the yellow will predominate, and, at the equator, will remain alone sensible, the expression for T then becoming $\mathrm{T} = \mathrm{Y} + y$, at the points C, *a*, *b*, D. Let us next consider the case when $\cos 2\,\phi = o$, or $\phi = 45°$, that is to say, along the axes or most intense lines of the lateral brushes. In this case we have

$$\mathrm{T} = \mathrm{B} + (y . \sin \nu^2 + b . \cos \nu^2) = (\mathrm{B} + b . \cos \nu^2) + y . \sin \nu^2.$$

Now if we suppose B and *b* to represent blue tints, since (in the case of iolite) the angle between the axes or $\mathrm{P\,P'} = 62° \, 50'$ and $\mathrm{O\,P} = 31° \, 25'$, we have in the immediate vicinity of the poles, $(\sin \nu)^2 = \frac{1}{4}$ nearly, and $\cos \nu^2 = \frac{3}{4}$, so that in the immediate neighbourhood of P the tint of the most intense part of the brushes will be $\mathrm{B} + \frac{3}{4} b + \frac{1}{4} y$, which, on very reasonable suppositions of the numerical values of B, *b* and *y* will denote a full and rich blue. But as we approach the equator at *m*, *n*, *p*, *q*, $\cos \nu^2$ diminishing and $\sin \nu^2$ increasing, the sombre tint B is continually more feebly reinforced by the tint $b . \cos \nu^2$ and more strongly counteracted by $y . \sin \nu^2$, till at length it will be overpowered, and the colour in these points, as in C, *a*, D, *b*, will be yellow only somewhat less decided than in the latter, its tint being represented by $\mathrm{T} = y + \mathrm{B}$ instead of $y + \mathrm{D}$.

1074. Determination of the coefficients from the observed tints.

In general, if we put A for the tint transmitted along the axis O of the prism, P for that seen along the poles, L for that of the lateral branches at their origin close to the poles, and E for the mean equatorial tint, we shall have for determining Y, *y*, B, *b*, the equations

$$\mathrm{A} = \mathrm{Y} + b, \quad 2\,\mathrm{E} = 2\,y + \mathrm{B} + \mathrm{Y},$$

$$\mathrm{P} = \mathrm{Y} + y . \sin a^2 + b . \cos a^2; \quad \mathrm{L} = \mathrm{B} + y . \sin a^2 + b . \cos a^2,$$

on elimination from these, it will appear that there is an equation of condition to be satisfied, *viz.*

$$2\,(\mathrm{A} - \mathrm{P}) = (2\,\mathrm{A} - 2\,\mathrm{E} \quad \mathrm{P} + \mathrm{L}) . \sin a^2; \quad (c)$$

and that supposing it satisfied, one of the tints, as y, will (so far as these conditions are concerned) remain arbitrary, and the others will be given by the equation

$$\left.\begin{array}{l} 2\,Y = 2\,E + P - L - 2\,y \\ 2\,B = 2\,E - P + L - 2\,y \\ 2\,b = 2\,A - 2\,E - P + L + 2\,y \end{array}\right\} ; \; (d)$$

in which y must, however, be such as to render Y, B, b real tints, *i. e.* expressed by positive numbers.

1075. Application to the iolite. To apply this, for example's sake, to the case of the iolite, let us regard every white ray as consisting of two complementary rays of bright yellow and bright blue of equal efficacy; and suppose that by observation we have ascertained its equatorial tint E to be a very pale but strongly luminous yellow white, consisting of 110 such yellow rays, and 99 such blue ones, producing a joint intensity = 209. Moreover, let the tint seen along the axis of the prism (A) be a blue, of a good colour, but considerably less intensity, represented by 10 such yellow + 20 such blue rays = 30. That seen along the optic axes (P) to be a white represented by 36 yellow + 36 blue = 72, and that of the most intensely coloured portions of the lateral brushes = L to be a stronger blue than that seen in the axis of the prism, such as may be represented by 28 yellow + 66 blue = 94. These numbers are chosen so as to satisfy the equation of condition, taking $a = 30°$, and if we substitute them we shall find

$$y + y = 114 \text{ yellow} + 84 \text{ blue}; \quad B + y = 106 \text{ yellow} + 114 \text{ blue}; \quad y - b = 104 \text{ yellow} + 64 \text{ blue},$$

y remaining indeterminate; if we suppose its composition to be m yellow + n blue, we may determine m and n by the two conditions that b shall (as we have before supposed) represent, a pure blue without any mixture of yellow, and Y a very pale yellow, such as would result from a mixture of yellow and blue in the ratio of 10 to 9. These conditions are satisfied by taking $m = 104$ and $n = 75$; so that we have, finally,

$$Y = 10 \text{ yellow} + 9 \text{ blue}; \qquad B = 2 \text{ yellow} + 39 \text{ blue};$$
$$y = 104 \text{ yellow} + 75 \text{ blue}; \qquad b = 0 \text{ yellow} + 11 \text{ blue};$$

and these being taken for the values of the coefficients in the expression (b) Art. 1073, it will be found on trial to reproduce the tints actually observed. In fact, the extreme equatorial tints being $y + Y$ and $y + B$, will be respectively represented by 114 yellow + 84 blue, and 106 yellow + 114 blue; the former is a very pale yellow, but highly luminous, being equivalent to 30 rays of yellow diluted with 168 of white; while the latter is a blue so pale as to be undistinguishable from white, and also highly luminous, being equivalent to 8 rays of blue diluted with 212 of white.

1076. Phenomena exhibited by various crystals. The reader will perceive that the formula in question is merely empirical, and that more numerous experiments than we possess will be required to establish or disprove it. It is unfortunately, however, difficult to meet with biaxal crystals sufficiently dichromatic for the purposes of decisive experiment, and at the same time large and transparent enough to admit of being cut into the forms and examined in the directions required, through a thickness sufficient for a full developement of their colours. Such are indeed hardly less rare than the most precious gems; and this circumstance is a great obstacle to the advancement of our knowledge in one of the most interesting branches of optical inquiry, which that of dichroism certainly deserves to be considered. Among artificial crystals, however, there is room to suppose that subjects fit for such experiments may be met with. One remarkable instance of dichroism among these has been mentioned in the sub-oxysulphate of iron. To this we may add the potash-muriate of palladium, which exhibits along the axis of the four-sided prism in which it crystallizes a deep red, and in a transverse direction a vivid green. (Wollaston, *Phil. Trans.* 1804. On a new metal in Crude Platina.) The curious property of the purpurates of ammonia, potash, &c. described by Dr. Prout, (*Phil. Trans.* 1808,) which by transmitted light exhibit an intense red, and by reflected, on one surface, a dull reddish brown, and on another a splendid green, appears referable, not so much to the principles of dichroism properly so called, as to some peculiar conformation of the green surfaces, producing what may be best termed a *superficial colour*, or one analogous to the colour of thin plates, and striated or dotted surfaces. A remarkable example of such superficial colour, differing from the transmitted tints, is met with in the green fluor of Alston-moor, which on its surfaces, whether natural or artificial, exhibits, in certain lights, a deep blue tint, not to be removed by any polishing.

1077. Unequal effects of heat on the colours of the two pencils. Dr. Brewster has shown that the action of heat often modifies in a very remarkable manner the colour of doubly refracting crystals, producing a permanent change in the scale of absorption of the crystals as affecting one of the pencils and not the other. Thus, having selected several crystals of Brazilian topaz which displayed no change of colour by exposure to polarized light, (and in which, of course, the types of both absorptions must have been alike,) and bringing them to a red heat, or even boiling them in olive oil, or mercury, they experienced a permanent change, and had acquired the property of absorbing polarized light unequally. He then took a topaz in which one of the pencils was yellow and the other pink; and by exposing it to a red heat, he found the extraordinary pencils more powerfully acted on than the ordinary, the yellow colour being discharged entirely from the one, while only a slight change was produced in the pink tint of the other. This change of colour in the topaz by heat (though not its intimate nature) is well known to jewellers, who are in the habit of thus developing in this gem a colour more highly prized. It is remarkable, that while hot the topaz is perfectly colourless, and acquires the pink colour gradually in cooling. By the repeated action of very intense heat Dr. Brewster was never able to modify or remove this permanent pink tint. How far violent compression, slow application, and abstraction of the heat, or other modifying circumstances, might prevent its developement, it hemitrope films, passing through the longer diagonals of opposite faces of the primitive rhomb. **If we look at** a candle through such an interrupted rhomb, it will be seen accompanied by a pair of lateral images such as here described, and exhibiting frequently the complementary tints with great splendour.

1081. Phenomena of idiocyclophanous crystals. If the luminary from which the ray S a issues be small, the lateral images will be separated by a dark interval from each other and from the central one, but if large they will overlap. If infinite (as where the uniform light of the sky is viewed) all the images will be superposed. But the field of view will not necessarily be uniform and white. The central image will form an intense white screen, or ground, on which will be projected the lateral ones. Now, if the film be so constituted as to have within the visible field of view of one only of the lateral images the pole of one of its sets of rings, (which will be the case whenever one of its optic axes is not very remote from perpendicularity to the surface of the plate A D, so as to admit of one of the rays O E or E O traversing the film in the direction of its axis,) that set of rings will not be seen projected centrally on the corresponding set complementary to it of the other lateral image, by reason of the angular separation of these two images. Of course its colours will not be neutralized, and it will be visible *per se*, though very faint, being diluted by the whole white light of the central image (O O, E E) and by the whole visible and nearly uniform portion of the other lateral one (O E.)

1082. Fig. 211. This is not the only way in which a crystal perfectly colourless may exhibit its sets of rings by exposure to common daylight without previous polarization, or without subsequent analysis of the transmitted pencil. The general mass of the crystallized plate may have one of its optic axes in the direction of the visual ray, as fig. 211, and the portion of it C D d c included between two films B C c b and D d e E will then form precisely such a combination as that above described, and will exhibit a set of rings feeble in proportion to the rarity and minuteness of the films, and the consequently small area of their outcropping surfaces B C, D E. These are not hypothetical cases. Dr. Brewster states himself to have met with specimens of nitre exhibiting their rings *per se*. Such are rare. But in the bicarbonate of potash it is an accident of continual occurrence; and, indeed, almost universal. The films in both cases are easily recognised, and their position and that of the system of rings seen leave no doubt of the correctness of the explanation here given. Such crystals, of which more will no doubt be hereafter recognised, may be termed *idiocyclophanous* till a better term can be thought of.

§ XII. *On the effects of Heat and Mechanical Violence in modifying the action of Media on Light, and on the application of the Undulatory Theory to their explanation.*

1083. General account of the phenomena. It was ascertained independently, and about the same time by Dr. Seebeck and Dr. Brewster, that when glass, which in its ordinary state offers none of the phenomena of double refracting media, is heated or cooled unequally, it loses this character of indifference, and presents phenomena of coloration, &c. analogous, in many respects, to those exhibited by doubly refracting crystals. If the heat communicated be below the temperature at which glass softens, the effect is transient, and vanishes when the glass attains a uniform temperature throughout its substance, whether by the equable distribution of the caloric throughout its mass, or by its abstraction in cooling. But if the temperature communicated be so high as to allow the molecules of the glass to yield to the mechanical forces of dilatation and contraction produced in the act of cooling and take a new arrangement, the effect is permanent, and glass plates so prepared have many points of resemblance with crystallized bodies. Dr. Brewster afterwards ascertained, that mechanical compression or dilatation applied to glass, jellies, gums, and singly refractive crystals (such as fluor spar, &c.) is capable of imparting to them the same characters. If the medium to which the pressure is applied be perfectly elastic, like glass, the effect, like that of heat, is transient. But if during the continuance of the compression or dilatation, the particles of the medium are allowed to take their own arrangement and state of equilibrium, then when the external force is withdrawn a permanent polarizing character will be found to exist.

1084. Accompanied by double refraction. As periodical colours are not produced in phenomena of this class without a resolution of the incident light into two pencils moving with different velocities, and as a difference of velocities is invariably accompanied with a difference of refraction at inclined surfaces, it might be expected that media thus under the influence of heat or pressure should become doubly refractive. This has been verified by direct experiment by M. Fresnel, who has shown that a peculiar species of double refraction is thus produced.

1085. Effect of heat analogous to that of pressure. As the unusual heating or cooling of glass and other substances, is well known to produce in the parts heated or cooled a corresponding inequality of bulk, and thus to bring the parts adjacent into a state of strain in all respects analogous to that arising from mechanical violence, and as, in fact, the effects of heat in communicating double refraction to glass, whether transient or permanent, are all, as we shall see, (with one very obscure and doubtful exception) commensurate with the amount of the strain thus transiently or permanently induced, we have little hesitation in regarding the inequality of temperature as merely the remote, and the mechanical tension or condensation of the medium as the proximate cause of the phenomena in question, and are very little disposed to call in the agency of a peculiar crystallizing fluid, endowed with properties analogous to those of magnetism, electricity, &c., to account for the phenomena, still less to regard media under the influence o heat or pressure as in any way thereby rendered more crystalline than in their natural state of equilibrium.

1086. In gasiform, or fluid media, no such phenomena are observed to be developed by either heat or pressure; t reason is obvious, the pressure is equally distributed in all directions, and the elasticity of the ether (on t undulatory hypothesis) preserves its uniformity.

But in solids the case is different. The molecules cannot shift their places one among the other, and t

Mode of action of pressure on the molecules of solids.

effect of a compression in any direction is, *first*, to urge contiguous particles nearer together in that direction, and thereby to call into action their repulsive forces, more than in the natural state, to maintain the equilibrium; secondly, but much more slightly to urge contiguous particles in a direction perpendicular to that of the pressure laterally *asunder*, by reason of the increase of the oblique repulsive force developed by the approach of the molecules in the line of pressure to those which lie obliquely to that line. But this action, which in fluids would cause a motion of the lateral particles out of the way, in solids is ultimately equilibrated by an increase of the attractive forces of the adjacent molecules in a line perpendicular to the line of pressure; and thus we see that every external force applied to a solid is accompanied with a condensation of its particles in the direction of the force and a dilatation in a perpendicular direction. It is probable, however, that this latter is extremely minute, on account of the rapid diminution of the molecular forces by increase of distance, rendering the diagonal action insensible. But the former may easily be conceived to produce in the ether, in virtue of its connection (whatever it be) with the molecules of refracting media, a difference of elasticity in the two directions in question, accompanied with all the necessary concomitants of interfering pencils, periodical colours, and double refraction The effect of dilatation will be the converse of that of compression, the direction of maximum elasticity in the one case being that of minimum in the other.

1087. Effects of compression described.

These views are in perfect accordance with the experiments described by Brewster and Fresnel on compressed and dilated glass. According to the former (*Phil. Trans.* 1816. vol. 106) the effect of pressure on the opposite edges of a parallelepiped of glass is to develope in it " neutral" and " depolarizing axes," the former parallel and perpendicular to the direction of the pressure, the latter 45° inclined to them; in other words, a parallelepiped of glass so compressed, will when exposed to a ray polarized in the plane parallel or perpendicular to the sides to which the pressure is applied, produce no change in its polarization and develope no periodical colours, while if polarized in 45° of azimuth with respect to those sides, it will develope a tint, descending in the scale of the coloured rings as the pressure increases.

1088. Explanation on the undulatory doctrine.

In this case, if the pressure be uniformly applied over the whole length of each opposite side, the elasticity of the ether in every point of the plate will be uniform in either direction at every point of the plate, being a maximum in one, and a minimum in that at right angles to it. The incident light therefore if polarized in azimuth a^0 will resolve itself into two pencils of unequal intensity (*viz.* cos a^2 and sin a^2) polarized in these two planes, and differing at their egress by an interval of retardation proportional to $t \times (v' - v)$, where t is the thickness traversed, and $v' - v$ the difference of velocities of the pencils, which when received on a double refracting prism will (as in the case of a crystallized plate (Art. 969) give rise to complementary periodical tints in the two images, the extraordinary image vanishing when $a = 0$, or 90, and the contrast being a maximum at 45°. It is, of course, extremely difficult to give such a perfect equality of pressure, so that we must not be surprised if a perfect uniformity of tint over the whole surface of the glass should not take place. In the experiment, however, described by Dr. Brewster (Prop. I. of the Memoir cited) this seems to have been the case.

1089.

If we suppose the elasticity of the ether in compressed glass *less* in the direction of the force applied (and where consequently the medium is densest, according to the general law) than in the perpendicular, the contrary will be the case in dilated. Hence, supposing the forces equal, in two similar plates, the extraordinary waves, or those whose vibrations are performed in the direction of the pressure, and which are therefore polarized at right angles to that direction, will advance most rapidly in the former case, the ordinary in the latter. Consequently, if we regard the interval of retardation or the tint, $t(v' - v)$ as negative in the former case, it will be positive in the latter; and the tints in the two cases will present the opposite characters of those exhibited by doubly refracting crystals of the two classes described in Art. 940, *et seq.* see also Art. 803, as negative and positive, or repulsive and attractive. Two such plates, therefore, placed homologously, or with the directions of the forces coincident, ought to neutralize each other, and if crossed at right angles should reinforce each other; and in general, if t be the thickness and f the compressing force applied to any plate (supposing the difference of velocities to be proportional to the force, and regarding dilating forces as negative) we shall have for homologously situated plates

Opposite effects of compression and dilatation.

$$\begin{aligned} \mathrm{T} &= \text{tint polarized by any number of plates} \\ &= (f.t + f'.t' + f''.t'' + \&\text{c.}) \end{aligned}$$

Law of superposition.

In the case of crossed plates the thicknesses of those placed transversely are to be regarded as negative, just as in the case of the superposition of crystallized plates. All these results are conformable to the experiments of Dr. Brewster.

1090. Tints produced by bending a glass plate.

The phenomena of contracted and dilated glass may most easily and conveniently be produced by bending a long parallel plate of glass having its longer edges polished, and passing the light through them across its breadth. In this case, as in all cases of flexure, the convex surface is in a state of dilatation, and the concave of compression, while there exists a certain intermediate line or boundary between these oppositely affected regions in which the substance is in its natural state of equilibrium, and on both sides of which neutral line the degree of strain increases as we *recede* from it towards either surface. Fig. 212 is a section of such a bent plate, much exaggerated, through which light, polarized in a plane 45° inclined to its length, has been passed and analyzed as usual. The neutral line is marked by a divided black stripe, and the tints on either side of it descend in Newton's scale, being arranged in stripes disposed according to the lines 11, 22, 33, 44, &c. The tints, however, on opposite sides of the neutral line have opposite colours, being positive on the side of the dilatation, or towards the convexity, and negative on the compressed or concave side. In a plate of glass 1.5 inch broad, 0.28 thick and six inches long, Dr. Brewster developed seven orders of colours before the glass broke with the bending force applied. This experiment affords an exceedingly beautiful illustration of the action of compressing and bending forces on solids, and furnishes ocular evidence of the state of strain into which their several parts

Fig. 212.

State of strain ascertained by the tints are brought by external violence. The ingenuity of Dr. Brewster has not overlooked its application to the useful and important object of ascertaining the state of strain and pressure on the different parts of architectural structures, as stone bridges, timber framings, &c., by the use of glass models actually put together as the buildings themselves. We must recollect always, however, that the information thus afforded will only be distinct when the load intended to be sustained is many times the weight of the materials.

1091. Effects of several co-existing strains.

If a plate of glass be subjected to several distinct compressions and dilatations in different directions, Dr. Brewster finds, that its action will be the same as the combined action of several plates each subjected to one of the forces employed. Thus a square of glass compressed equally on all its four edges exerts no polarizing action.

1092. Pressure applied at a point.

If a pressure be applied at a single point of a mass of glass, or rather at two opposite points, it will diverge from these points in all directions into the mass, and the lines of equal pressure, which are in fact the isochromatic lines, must have their form determined in some measure by the figure of the compressing screw or tool at its point of contact with the glass, for this figure regulates the form and curvature of the indentation immediately under it. Dr. Brewster has figured several of the curves produced by the application of such pressure to different parts of the same parallelepiped of glass, for which the reader is referred to his Paper, as well as for a variety of beautiful figures produced by crossing plates differently strained.

1093. Effects of vibration.

M. Biot has observed, that in some instances glass maintained in a state of vibration by the action of a bow or otherwise, depolarizes light, *i. e.* restores the vanished pencil. This is a necessary consequence of the alternate compressions and dilatations which follow each other in rapid succession in all the vibrating molecules. Nodal lines (see ACOUSTICS) being exempt from such variations of density ought to be marked by black bands, and may thus, perhaps, be rendered evident to the eye.

1094. Polarization by compressed jellies

When masses of jelly (especially of isinglass) are pressed between plates they acquire a polarizing action. If dilated by proper management, and in that state allowed to dry and harden, the character so impressed, according to Dr. Brewster, is permanent when the dilating force is removed; to explain which, we must consider that the exterior coats indurate more rapidly than the interior, and when they have acquired the consistency of a solid, they will be capable of resisting the subsequent contraction of the interior portions and keeping them in a dilated state, even when the original dilating force is removed. That force only served to determine the figure and dimensions of the exterior crust, and when once that crust is fully formed and indurated, it becomes capable of maintaining them without the further aid of the cause which gave them rise. The polarizing power of isinglass thus developed is very great, and even exceeds that of some doubly refractive crystals, such as beryl; a plate of isinglass whose thickness is 624 polarizing the tint which would be reflected by a plate of air whose thickness is unity, while a plate of beryl parallel to the axis, to polarize the same tint, will require a thickness = 720. Glass compressed, or dilated, by an equal force, would require a thickness (according to Dr. Brewster) = 12580 to produce the same tint.

1095. Transient effects of heat below the softening point.

We come now to consider the transient effects of unequal temperature below the softening point of glass. The immediate effect of an increase or diminution of temperature in one point of a piece of glass, is to produce a mechanical strain on all the surrounding part, which if the difference of temperature is considerable, is of the utmost violence, and capable of breaking asunder the thickest pieces of glass; an effect with which every one is familiar. Now, as we know that strain alone developes a polarizing action, the rule of philosophy, "*non plures causas admitti debere,*" *&c.* which forbids the admission of a second cause when one adequate to the effect is known to be in action, will hardly justify us in attributing a peculiar action to the caloric, independent of its power of altering the dimensions of matter.

1096. Case of a rectangular plate of glass heated at one edge.

When a heated iron bar is applied along the edge of a parallelepiped of glass held in a polarized beam, analyzed as usual, the vanished image is restored in various degrees of intensity in different parts of the glass. The *neutral axes* are parallel and perpendicular to the heated edge, and the axes in whose azimuth the tint polarized is the strongest, at 45° of inclination. If held in that azimuth, the first effect of the heat is to produce a line, or, as it were, a wave of white light at the heated edge, which advances gradually upon the glass, driving before it a dark and undefined wave. Nearly at the same instant, and *long before the slightest increase of temperature can have reached the further extremity of the glass plate*, a similar but fainter white wave advances from the edge opposite to the heated one, driving before it a similar undefined dark wave; and at no perceptible interval of time another white fringe appears in a very diluted state about the centre of the plate, advancing equally towards the heated edge on one side and that most remote on the other, and thus condensing the two undefined dark waves into two black fringes. The white tints are succeeded by tints of a lower order in the scale of colour, yellow, red, purple, blue, &c., till at length the whole scale of the colours of thin plates is seen arranged in four sets of fringes parallel to the heated edge, and having for their origins the black fringes above mentioned. At the same time, other lateral fringes are produced along the edge perpendicular to the heated one. Thus in all six sets are seen; two *exterior*, *viz.* those parallel to the heated edge, and *outside* of the black fringes; two *interior*, in the same direction, but between the black fringes; and two *terminal*, along the lateral edges. Fig. 213. The whole phenomena is as represented in fig. 213. The fringes along the heated edge A B are most distinct and numerous, those along the opposite, C D, less so, and the interior and terminal fringes least of all.

1097. Action of heat in straining the glass.

As glass is an extremely bad conductor of heat, and as culinary heat is propagated through glass *entirely* by conduction, it follows, that the sudden application of an elevated temperature to the edge A B must produce a dilatation in it, not participated in by the rest of the glass. If, therefore, the stratum of molecules A B were detached from the rest of the glass, it would elongate itself so as to project at its two ends beyond the edges A C, D B. When the heat of this stratum communicated itself to the next, that also would elongate itself, but in a less degree; and thus after a very long time, during which the heat had penetrated to the farther extremity of the glass, its outline would assume the form *a* C D *b*, the lines *a* C, *b* D being certain curves depending on the law of propagation and the time elapsed. This would be the state of things were the glass plate composed of *discrete* strata, each of which could dilate independently of all the rest. And since in each of these (regarded as infinitely thin) the temperature and strain would be uniform, there would arise no polarizing action. But, in reality, the case is quite different; every stratum is indissolubly connected along its whole extent with the strata adjacent, and can neither expand nor contract without forcing them to participate in its change of dimension. In so far, then, as two adjacent strata participate in the change of temperature they expand together; but when one is hotter than the other, the former is found to expand *less*, and the other *more* than if they were independent. Now the strain thus induced on any stratum is not, like the caloric which causes it, confined by the conducting power of the medium, but propagates itself *instantly* (with diminished energy) to the strata beyond, by reason of the mutual action of the molecules.

1098. State of the various regions of the plate as to strain determined. Fig. 214.

The general problem, then, to investigate the actual state of strain of any molecule at any moment is one of some complexity, inasmuch as it depends at once on the laws of the slow propagation of heat, and the instantaneous but variable participation of change of figure necessary to establish among the particles a momentary equilibrium under the circumstances of temperature at the time; but, without attempting minutely to analyze the effects, if we content ourselves with acquiring a general idea how they arise, we shall find little difficulty. For in fig. 214, if we conceive the stratum A B b a adjacent to the border A B to be dilated by the heat, the rest of the glass retaining its original temperature; if this stratum could expand separately, its edges A a, B b would project out beyond the general edges C α, D β; and if we regard two terminal strata C A E G, D B F H, as detached from the interior portion C D β α, and free to move by the force applied at their extremities A, B, they would be raised by the dilatation of the portion A B b a into the situation represented in the figure, turning round C, D as fulcrums, and leaving triangular intervals C a α, D b β vacant, and in these circumstances there would be no strain on any part of the system. But the cohesion of the glass prevents the formation of these vacancies, and the bars or levers C A E G, D B F H cannot move into this situation without dragging with them, and therefore distending the strata of C D β α. Let P Q be any such stratum, and let it be distended to p q. Then by its elasticity it will tend to draw the bars C A E G and B D H F together; and its action will therefore tend, first, to produce a pressure on the fulcrums C, D, urging the points C D together, and therefore bringing the stratum C D into a state of compression. Secondly, to produce also a pressure on A a, B b, or a resistance to the dilatation of A B b a, which its increased temperature would naturally produce. It will therefore tend to *compress back* the strata of A B b a into a smaller length than what would be natural to them in their heated state, *i. e.* to bring *them* also into a relatively compressed state. Thirdly, the tension of p q being sustained at C, D and A, B, will tend to bend inwards the levers A C G E, B D H F, rendering them concave at the edges G E, H F, and convex at C A, D B, and thus distending the lines C A, D B, and compressing the strata adjacent to E G, H F.

1099. Production of fringes of opposite characters. Fig. 215.

From this reasoning it is clear, that the glass, in consequence of these various strains, will assume a figure concave on all its edges, but chiefly so at the lateral ones A C, D B, as in fig. 215; and that the state of strain of its various parts will be as there expressed, all the edges being compressed, but principally A B and C D, and the interior distended. The limit between the distended and compressed portions parallel to A B must necessarily be marked by neutral lines a b, c d on either side of which the strain will increase, being a maximum in the middle and on or near the edges. Consequently, it ought to polarize four sets of fringes, having a b, c d for their origins, and of which the two external (or those between these lines to the edge) ought to have a character opposite to those of the internal, the portion of the intromitted pencil polarized parallel to A B being propagated faster than that parallel to A C in the one case, and slower in the other. This opposition of characters is conformable to Dr. Brewster's observations, who states (*Phil. Trans.* 1816) that the parts of the glass which exhibit the two exterior sets of fringes (adjacent to the edges A B, C D) have "the structure of" attractive crystals, while the parts which exhibit the interior and terminal sets have that of repulsive ones; meaning, of course, in the language of the undulatory doctrine, that the order of velocities of the doubly refracted pencils is reversed in passing from one region of the glass to the other, for of its actual structure we can know nothing. That the terminal fringes ought (as observed) to have the same character as the interior is a necessary consequence of the above reasoning, for the terminal regions D B, A C are compressed in directions *parallel* to their edges, and therefore *perpendicular* to the direction in which the central portion is distended; and we have already seen that compression in one direction is equivalent (so far as the character of the tints produced is concerned) to distension in that perpendicular to it.

The terminal fringes.

1100. Neutral lines separating adjacent sets of fringes.

Lastly, the black lines separating the terminal fringes from the interior ones, arise from the combined action of the tension of the interior region parallel to A B (fig. 214) exerting itself on any point as q on the inner border of the terminal portion D B F H, (which we have regarded as an elastic bar, or lever,) and the distension of the line D B also exerting itself at q, and arising from the convexity given to this line. In virtue of these two forces, every point q in a certain line at a proper distance from the extreme edge H F, will be equally distended in opposite directions, and will therefore be in a neutral state, as to polarization, and, of course, appear black. The terminal fringes are less developed than the rest, because they arise simply from the flexure of the edges H F, G E, which is an indirect effect of the principal force, and is very small, (owing to the small dilatability of glass by heat, and consequent minuteness of the versed sine of the curve into which they are distorted,) and the line of indifference separating them from the others lies near the edges; for the same reason, the tension of the convex line D B being small, and therefore putting itself in equilibrium with that of the distended column p q at a point q near its extremity, where it is evident that the strain parallel to p q must be much diminished; the greater portion of the whole tension of p q being resisted by the spring of laminæ situated still further from the edge than D B.

1101

If a lamina of glass, uniformly heated, be suddenly cooled at one of its edges, the reverse of all these effects will arise; the outer column A B a b (fig. 214) will suddenly contract and compress violently the columns

Phenomena of a heated glass rectangle cooled at one edge.

beyond $\alpha\beta$, from which no heat has yet been abstracted, and drag inwards the ends of the terminal levers E A G C, B F H D, which will thus be violently pressed on the parts β Q and α P as fulcra; and their action being thus transmitted to the opposite edge C D will tend to lengthen it, and thus bring it, as well as the edge A B, into a distended state. The terminal edges will also be sprung outwards. The strain on every point will be exactly the reverse of what is expressed in fig. 215, and a corresponding inversion of the characters of the tints will take place; all which is agreeable to Dr. Brewster's observation, (Prop. 14 of the *Memoir* cited.)

1102. Effect of a crack.

When a crack takes place in a piece of unequally heated glass, the directions and intensities of the straining forces in every part, which depend wholly on the cohesion of its molecules, and the continuity of the levers, springs, &c. into which it may be mentally conceived to be divided, is suddenly altered; and the fringes are accordingly observed to take instantly a new arrangement, and assume forms related to the figure of that part of the glass which preserves its continuity. To analyze the modifications arising from variations of external figure and different applications of the heat, would be to involve ourselves unnecessarily in a wilderness of complexity. One simple case may, however, be noticed, in which the centre of a circular piece of glass is heated.

Case of a circular plate heated in the centre.

Each exterior annulus of this will be placed in a state of distension parallel to its circumference, and will compress all within it by a force parallel to the radius. The central point will be neutral, being equally confined in all directions, and the annuli adjacent to the centre will in like manner be compressed both radially and circumferentially. The radial strain continues as we recede from the centre, but the circumferential diminishes, and at length, as already said, changes to a state of distension, and of course passes through a neutral state, thus giving rise to a black circle and concentric fringes of opposite characters, the whole of which will be intersected by the arms of a black cross parallel and perpendicular to the plane of primitive polarization, and which of course remains fixed while the plate is turned round in its own plane.

1103. Singular effect of a crack allowed to close.

There is only one experiment of Dr. Brewster which seems hostile to the theory here stated. He made a partial crack with a red-hot iron in a very thick piece of glass, and allowed it to close by long standing, which it did, so as to disappear entirely. In this state, the glass, when unequally heated, exhibited the same fringes, as if no crack had existed; but the moment the crack was opened by a slight heat applied near it, they suddenly changed their figure, and assumed that due to the portion having the crack for a part of its outline. It seems, however, that a very great adhesive force takes place between the surfaces of glass when thus in optical contact; and to those who are aware how the free expansion and contraction of dissimilar metallic bars may be commanded, and the bars in consequence made to ply on change of temperature by mere forcible juxtaposition, without soldering, till the difference of expansion has reached a certain point, when they give way with a snap and regain their state of equilibrium, the anomaly will not appear in the light of a radical objection. *(We think it not improbable that the musical sounds said to issue at sunrise from certain statues, may originate in some pyrometrical action of the kind here alluded to. We have often been amused by a similar effect produced in the bars of the grate of a fire-place.)*

1104. Phenomena of unannealed glass

Such are, in general, the transient effects of a heat below the softening point of glass, unequally distributed through its substance. But if a mass of glass be heated up to, or beyond that point, so as to allow its molecules to glide with more or less freedom on one another, and adapt themselves to any form impressed on the mass, and then suddenly cooled, either by plunging into water, or by exposure to cold air, the heat is abstracted from its external strata with so much greater rapidity than it can be supplied by conduction from within, that they become rigid, while the inner portions are still soft and yielding. At this instant, there is therefore no strain in any part; but, the abstraction of the heat still going on, the internal parts at length become solid, and tend, of course, to contract in their dimensions. In this, however, they are prevented by the external crust already formed, which acts as an arch or vault, and keeps them distended, at the same time that these latter portions themselves are to a certain extent forced to obey the inward tension, and are strained inwards from their figure of equilibrium. Glass in this state is said to be unannealed. If the cooling has been sudden, and the mass considerable, it either splits in the act of cooling, or flies to pieces, when cold, spontaneously, or on the slightest scratch which destroys the continuity of its surface; and the pieces when put together again (which, however, is seldom practicable, as it usually flies into innumerable fragments, or even to powder, as is familiarly shown

Rupert's drops.

in the glass tears called Rupert's drops, which exhibit a very high polarizing energy from their intense strain, and which burst with a violence amounting to explosion, on the rupture of their long slender tails) are found not to fit, but to leave a slight vacancy; thus satisfactorily proving the state of unnatural and violent distension in which its internal parts have been held. The case is precisely analogous to that of a gelatinous substance allowed to indurate under the influence of dilating forces. (See Art. 1094.)

1105. Patterns exhibited by circular, square, and rectangular unannealed plates. Fig. 216—221.

If the cooling be less sudden, and carefully managed, the glass, though much more brittle than ordinary annealed glass, is yet susceptible (with great caution) of being cut and polished; and in this state, if polarized light be passed through it, it exhibits coloured phenomena of astonishing variety and splendour, forming fringes, irises, and patterns of exquisite regularity and richness, according to the form and size of the mass, and the degree of strain to which it is subjected. In all these cases if the external form be varied, the pattern varies correspondingly, as it is easy to perceive it ought; for if any part of the exterior crust be removed, that part of the strain which it sustained will fall on the remainder, and on the new surface produced. Figures 216, 217, and 218, represent the patterns exhibited by a circular, a square, and a rectangular plate of about $\frac{1}{3}$ inch thick, the two latter being placed so as to have one side parallel to the plane of primitive polarization. Figure 219 and 220 represent the patterns shown by the two latter in azimuth 45°, and fig. 221 that arising from the crossing of two plates equal and similar to fig. 220, each being in azimuth 45°. In all these cases the laws of superposition of Art. 1089 are observed, when similar points of similar plates are laid together. If symmetrically, the tints polarized is the same as would be polarized by one plate whose thickness is their sum; if crosswise, their difference.

starting up and separating itself from the rest, till, in a few moments, the whole is resolved into a heap of incoherent powder, a result which could evidently not take place, had all the minute and interlaced crystals of which the congealed salt consisted contracted equally in all directions by the cooling process, as in that case their juxtaposition would not be disturbed. Phenomena somewhat similar, and referable to the same principles, have (if we remember right) been encountered by M. Achard in the fusion of various frits for glasses, &c.

1112. Double refraction of crystals variable with temperature. Remarkable property of sulphate of lime.

The relation of the optical and crystallographical characters of bodies is so intimate, that no change can be supposed to take place in the latter without a corresponding alteration in the former. As the rhomboid of Iceland spar becomes less obtuse by heat, and therefore approximates nearer to the cube, in which the double refraction is nothing, it might be expected that the power of double refraction should diminish, and this result has been verified by M. Mitscherlich by direct measurement. More recently, the same distinguished chemist and philosopher has ascertained the still more remarkable and striking fact, that the ordinary sulphate of lime or gypsum, which, at common temperatures, has two optic axes *in* the plane of its laminæ, inclined at 60° to each other, undergoes a much greater change by elevation of temperature; the axes gradually approaching each other, collapsing into one, and (when yet further heated) actually opening out again in a plane *at right angles* to the laminæ, thus affording a beautiful exemplification of Fresnel's theory of the optic axes as above explained.

1113 This singular result we cite from memory, having in vain searched for the original source of our information; but it might have been expected, from the low temperature at which the chemical constitution of this crystal is subverted, by the disengagement of its water, that the changes in its optical relations by heat would be much more striking than in more indestructible bodies. We have not, at this moment, an opportunity of fully verifying the fact; but we observe, that the tints developed by a plate of sulphate of lime now before us, exposed as usual to polarized light, rise rapidly in the scale when the plate is moderately warmed by the heat of a candle held at some distance below it, and sink again when the heat is withdrawn, which, so far as it goes, is in conformity with the result above stated. Mica, on the contrary, similarly treated, undergoes no apparent change in the position of its axes or the size of its rings, though heated nearly to ignition. The subject is in the highest degree interesting and important, and lays open a new and most extensive field for optical investigation. It is in excellent hands, and we doubt not will, ere long, form a conspicuous feature in the splendid series of crystallographical discovery which has already so preeminently distinguished its author

§ XIII. *Of the Use of Properties of Light in affording Characters for determining and identifying Chemical and Mineral Species, and for investigating the intimate Constitution and Structure of Natural Bodies.*

1114. Relation between the refractive powers and chemical composition of bodies.

Newton, who "looked all nature through," was the first to observe a connection between the refractive powers of transparent media and their chemical properties. His well known conjecture of the inflammable nature of the diamond, from its high refractive power, so remarkably verified by the subsequent discovery of its one and only chemical constituent, (*carbon*,) was, perhaps, less remarkable for its boldness, at a period when Chemistry consisted in a mere jargon, in which *salt*, *sulphur*, *earth*, *oil*, and *mercury* might be almost indifferently substituted for one another, than it would have been fifty years later. His divination of the inflammable nature of one of the constituents of water is at least equally striking as an instance of sagacity, and even more remarkable, for the important influence which its verification has exercised over the whole science of Chemistry. These instances suffice to show the value of the refractive index, either taken in conjunction with the specific gravity of a medium, or separately as a physical character. The refractive indices of a vast variety of bodies have been ascertained by the labours of Newton and later experimenters, among whom Dr. Brewster and Dr. Wollaston have been the largest contributors to our knowledge. They may be grouped together in a general way, in order of magnitude, as follows:

1115. Classification of bodies according to their refractive densities.

Class 1. Gases and vapours. Refractive index from 1.000 to 1.002, under ordinary circumstances of pressure and temperature.

Class 2. $\mu = 1.05 \ldots\ldots \mu = 1.45$. Comprising the condensed gases; ethereal, spirituous, and aqueous liquids; acid, alkaline, and saline solutions, (not metallic.)

Class 3. Comprising, first, almost all unctuous, fatty, waxy, gummy, and resinous bodies; camphors, balsams, vegetable and animal inflammables, and all the varieties of hydro-carbon. Secondly, stones and vitreous compounds, in which the alkalis and lighter alkaline earths in combination with silica, alumina, &c. are the predominant ingredients. Thirdly, saline bodies not having the heavy metals, or the metallic acids predominant ingredients. $\mu = 1.40 \ldots\ldots 1.60$.

Class 4. Pastes, (glasses with much lead,) and, in general, compounds in which lead, silver, mercury, and the heavy metals, or their oxides abound. Precious stones, simple combustibles in the solid state, including the metals themselves.

$$\mu = 1.60 \text{ and upwards.}$$

These classes, however, admit of so many exceptions and anomalies, and are themselves so vague and indefinite, that we shall not attempt to distribute the observed indices under any of them, but rather prefer, for convenience of reference, presenting the whole list in the form of a Table, arranged in order of magnitude, in which all these classes are mingled indiscriminately—a form, in some measure, consecrated by usage.

Part IV.
1116.

Table of Refractive Indices, or Values of μ *for Rays of Mean Refrangibility, (unless expressed to the contrary.) Dr. Wollaston's results, however, are all (according to Dr. Young, Philosophical Transactions,* vol. xcii. p. 370,) *to be regarded as belonging to the Extreme Red Rays.*

N. B. In this Table the authorities are referred to as follows:

Br. Brewster, *Encyclop. Ed.*, and Treatise on *New Philosophical Instruments.* Bos. Boscovich.
B. Y. Dr. Young's Calculations of Dr. Brewster's Unreduced Observations. *Quarterly Journal,* vol. xxii.
Bi. Biot. F. Faraday. Du. Dulong. M. Malus. N. Newton. Fr. Fraunhofer.
W. Wollaston, *Phil. Trans.* He. From our own observation. Eul. Euler the younger.
C. and H., authorities cited by Dr. Young in his *Lectures.*

Vacuum	1.000000	

GASES,

at the freezing temperature and pressure $= 29^{in}.922 = 0^{m}.76$.

Hydrogen	1.000138	Du.
Oxygen	1.000272	Du.
Atmospheric air	1.000294	Bi.
Azote	1.009300	Du.
Nitrous gas	1.000303	Du.
Carbonic oxide	1.000340	Du.
Ammonia	1.000385	Du.
Carburetted hydrogen	1.000443	Du.
Carbonic acid	1.000449	Du.
Muriatic acid	1.000449	Du.
Hydrocyanic acid	1.000451	Du.
Nitrous oxide	1.000503	Du.
Sulphuretted hydrogen	1.000644	Du.
Sulphurous acid	1.000665	Du.
Olefiant gas	1.000678	Du.
Chlorine	1.000772	Du.
Protophosphuretted hydrogen	1.000789	Du.
Cyanogen	1.000834	Du.
Muriatic ether	1.001095	Du.
Phosgen	1.001159	Du.
Vapour of sulphuret of carbon	1.001500	Du.
Vapour of sulphuric ether (boiling point at 35° centig.)	1.001530	Du.

LIQUIDS AND SOLIDS.

	μ =	
Ether expanded by heat to three times its volume	1.0570	Br.
Tabasheer from Vellore, a yellowish transparent variety	1.1111	Br.
First new fluid discovered by Dr. Brewster in cavities in topaz	1.1311	Br.
Tabasheer, transparent, from Nagpore	1.1454	Br.
Ditto ditto ditto another specimen	1.1503	Br.
Ditto, whitest variety, from Nagpore	1.1825	Br.
New fluid discovered by Dr. Brewster in amethyst, at 83½° Fahr.	1.2106	Br.
Second new fluid discovered by Dr. Brewster in topaz, at 83° Fahr.	1.2946	Br.
Nitrous oxide liquefied by pressure	much less than water	F.
Muriatic acid gas ditto ditto Carbonic acid gas ditto ditto .. nearly equal..	both much less than water	F.
Ice	1.307 1.3085 1.3100	Br. Br. W.
Chlorine liquefied by pressure	rather less than water	F.
Cyanogen liquefied by pressure	perhaps less than water	F.
Ditto ditto	1.316	Br
Sulphurous acid liquefied by pressure	equal to water	F.
Water	1.336	N. W. Br.
Sulphuretted hydrogen liquefied by pressure	rather greater than water	F.
Ammonia liquefied by pressure	greater than water, and greater than all the other liquefied gases	F.
Aqueous humour of the eye	1.3366	Br.
Ditto of the haddock	1.341	B.Y.
Vitreous ditto	1.336	W.
Vitreous humour of the haddock	1.3394	Br.
Ditto	1.340	B.Y.
Ditto of the lamb	1.345	B.Y.
Ditto of the pigeon	1.353	B.Y.
Saliva	1.339	B.Y.
Expectorated mucus	1.339	B.Y.
Salt water (? sea water)	1.343	Br.
Cryolite	1.344 1.349	Br.
Vinegar (distilled)	1.344	Eul.
Ditto	1.372	H.
Vinegar	1.347	B.Y
Acetic acid (? strength)	1.396	Br.
Jelly fish (Medusa Æquora)	1.345	Br.
White of egg	1.351	Eul.
Port wine	1.351	B.Y.
Human blood	1.354	B.Y.
Saturated aqueous solution of alum	1.356	He.
Oil of box-wood	1.356	B.Y.
Ether	1.358 1.374	W. B.Y.
Albumen	1.360	W.
White of a hen's egg	1.361 1.359	Br. B.Y.
Brandy	1.360	B.Y.
Rum	1.360	B.Y.
Oil of ambergris	1.368 1.379	Br. B.Y.
Alcohol	1.37	W.
Ditto (S. G. 0.866)	1.370	N.
Ditto	1.371	C.
Ditto (rectified spirits)	1.372	He.
Ditto	1.374	Br.
Ditto	1.377	B.Y.
Saturated solution of salt	1.375	C.
Muriatic acid (? S. G.)	1.376	Br.
Ditto (S. G. 1.134)	1.392	He.
Ditto	1.395	B.Y.
Ditto (strong)	1.401	Br.
Ditto (highly concentrated)	1.4098	Bi.
Oil of wine	1.379	B.Y.
Sweet spirit of nitre	1.384	He.
Cornea of a lamb	1.386	B.Y.
Malic acid	1.395	Br.
Pus	1.395	B.Y.
Nitrous (?) acid (? strength)	1.396 1.404	Br. B.Y.
Nitric acid (? strength)	1.406	Br.
Crystalline lens of the eye (human?) outer coat	1.3767	Br.
Ditto ditto middle coat	1.3786	Br.
Ditto ditto centre	1.3990	Br.
Ditto of the lamb's eye, outer coat	1.386	B.Y.
Ditto ditto middle coat	1.428	B.Y.
Ditto ditto centre	1.436	B.Y.
Ditto of the haddock's eye, outer coat	1.410	B.Y.
Ditto ditto middle coat		
Ditto ditto centre	1.439	B.Y.
Ditto of the ox	1.380 1.447	W.
Ditto ditto	1.463	Eul.
Ditto of the pigeon	1.406	B.Y.
Juice of orange peel	1.403	B.Y.
Solution of potash, S. G. 1.416, (ray E)	1.40563	Fr.
Nitric acid (S. G. 1.48)	1.410 1.410	B.Y. W.
Nitric acid	1.412	C.
Hydrate of soda melted by heat	1.411	B.Y.
Hydrophosphoric acid ditto	1.423	B.Y.
Phosphoric acid (fluid)	1.426	Br

Light.

Gluten of wheat, dried	1.426	B. Y.
Fresh yolk of an egg	1.428	B. Y.
Sulphuric acid (S. G. 1.7)	1.429	N.
Ditto ditto (? S. G.)	1.430	He.
Ditto	1.435	W.
Ditto	1.440	Br.
Fluor spar	1.433 1.436	W. Br.
Oil of rhue	1.433 1.449	Br. B. Y.
Phosphorous acid	1.437	B. Y.
Hydrophosphoric acid, cold	1.441 1.442	B. Y. Br.
Spermaceti (melted)	1.446 1.454	W. B. Y.
Oil of wax	1.452	C.
Oil of wormwood	1.453	Br.
Bees wax, melted	1.453	B. Y.
Oil of chamomile	1.457	Br.
Ditto	1.476	B. Y.
Oil of lavender	1.457	Br.
Ditto	1.467	W.
Ditto	1.475	B. Y.
Alum	1.457	W.
Ditto (S. G. 1.714)	1.458	N.
Ditto	1.488	B. Y.
Tallow (melted)	1.460	W.
White wax (melted)	1.462	B. Y.
Oil of poppy	1.467 1.483	Br. B. Y.
Sulphate of magnesia (double? least refraction)	1.465	Br.
Borax, (S. G. = 1.714)	1.467 1.467 1.475	N. C. Br.
Oil of peppermint	1.468 1.473	W. B. Y.
Oil of rosemary	1.469 1.472	Br. B. Y.
Oil of spermaceti	1.470 1.473	Br. B. Y.
Oil of almonds	1.469 1.470	W.
Ditto	1.481 1.483	B. Y. Br.
Oil of turpentine, rectified	1.470	W.
Spirit of turpentine, (S. G. 0.874)	1.471	N.
Oil of turpentine	1.475	Br.
Ditto	1.476	B. Y.
Ditto (common)	1.476	W.
Ditto	1.482	C.
Ditto	1.485	B. Y.
Ditto (common)	1.486	He.
Ditto, S. G. = 0.885, (ray E)	1.47835	Fr.
Oil of olives	1.467* 1.469 1.470 1.4705 1.476	N. W. Br. He. B. Y.
Oil of bergamot	1.471 1.473	Br. B. Y.
Oil of beech, misprinted ? oil of brick	1.471	Br.
Oil of brick, distilled from spermaceti	1.470 1.471	B. Y. Br.
Oil of juniper	1.473	Br.
Butter, cold	1.474 1.480	B. Y. W.
Palm oil	1.475	B. Y.
Oil of rape seed	1.475	B. Y. Br.
Naphtha	1.475	B. Y.
Essence of lemon	1.476	W.
Gum arabic (S. G. = 1.375)	1.476	N.
Oil of dill seed	1.477	Br.
Oil of thyme	1.477	Br.
Oil of cajeput	1.478 1.483	B. Y. Br.
Opal (partly hydrophanous)	1.479	Br.
Naples soap	1.479	B. Y.
Oil of mace, melted	1.481	B. Y.

Oil of spearmint	1.481 1.496	Br. B. Y.
Oil of lemon	1.481 1.489	Br. B. Y.
Carbonate of potash (?)	1.482	Br.
Oil of pennyroyal	1.482	Br.
Ditto	1.485	B. Y.
Linseed oil (S. G. 0.932)	1.482	N.
Linseed oil	1.485	W.
Ditto	1.487	B. Y.
Oil of savine	1.482	Br.
Oil of juniper	1.482 1.491	B. Y.
Sulphate of ammonia and magnesia	1.483	Br.
Train oil	1.483	B. Y.
Oil of wormwood	1.485	B. Y.
Ditto	1.489	
Castor oil	1.485 1.490	B. Y. Br.
Florence oil	1.485	B. Y.
Oil of thyme	1.486	B. Y.
Oil of dill seed	1.487	B. Y.
Oil of feugreek (? fenugreek)	1.487	Br.
Ditto	1.488	B. Y.
Camphor	1.487	W.
	1.496	B. Y.
	1.500	C.
(S. G. = 0 996)	1.500	N.
Oil of hyssop	1.487 1.495	Br. B. Y.
Windsor soap	1.487	B. Y.
Obsidian	1.488	Br.
Iceland spar....weakest refraction	1.488 1.519	W. B.
Ditto ....strongest	1.657 1.665	W. Br.
Ditto ....ordinary index	1.6543	M.
Ditto ....extraordinary	1.4833	M.
Ditto ....(S. G. = 2.72)	1.667	N.
Sulphate of magnesia (? greatest refraction)	1.488	Br.
Nut oil (perhaps impure)	1.490	He.
Ditto	1.507	Br.
Oil of castor	1.490	Br.
Tallow (cold)	1.49— 1.492	W. B. Y.
Oil of carraway seed (carui seminis)	1.483 1.491	B. Y. Br.
Oil of marjoram	1.490 1.491	B. Y. Br.
Oil of nutmeg	1.491 1.497	B. Y. W.
Nut oil	1.491 1.507	B. Y. Br.
Oil of Angelica	1.491 1.493	B. Y. Br.
Bees wax, cold	1.492	B. Y.
Bees wax	1.507	B. Y.
Ditto 14° Reaum.	1.5123	M.
Ditto, melting	1.4503	M.
Ditto, boiling	1.4416	M.
Ditto	1.542	W.
Ditto (white wax, cold)	1.535	W.
Sulphate of iron, greatest refraction	1.494	Br.
Balsam of sulphur	1.494 1.497	B. Y. Br.
Sulphate of potash	1.475 1.509	W. Br.
Honey	1.495	B. Y.
Rochelle salt (mean green rays)	1.4985	He.
Ditto (mean red)	1.4929	He.
Ditto (tartrate of potash and soda)	1.515	Br.
Treacle	1.500	W.
Yolk of an egg (dry)	1.500	B. Y.
Oil of beech nut	1.500	Br.
Oil of rhodium	1.500 1.503 1.505	Br. B. Y. Br.
Glass, plate and crown, various specimens:		
Ditto English plate	1.500	W.
Ditto French plate	1.504	W.
Ditto English plate (extreme red)	1.5133	He.
Ditto plate	1.514	Bos.

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* The S. G. of Newton's specimen was 0.913.

Part IV.

Glass, Dutch plate	1.517	W.
Ditto crown, common	1.525	W.
Ditto plate	1.526	Bos.
Ditto crown, a prism by Dollond, (extra red)	1.526	He.
Ditto plate	1.527	Br.
Ditto ditto	1.529	Bos.
Ditto crown, another prism by Dollond, (extra red)	1.5301	He.
Ditto Fraunhofer's crown, No. 13, (ray E,) S. G. 2.535	1.5314	Fr.
Ditto yellow plate, S. G. 2.52	1.532	C.
Ditto Fraunhofer's crown, No. 9, (ray E,) S. G. 2535	1.5330	Fr.
Ditto Radcliffe crown	1.533 1.536	W.
Ditto crown	1.534	Br.
Ditto plate	1.538	Bos.
Ditto ditto	1.542	Bos.
Ditto St. Gobin	1.543	W.
Ditto crown	1.544	Br.
Ditto old plate	1.545	W.
Ditto vulgar	1.550	N.
Ditto Fraunhofer's crown, M, S. G. 2.756, (ray E)	1.5631	Fr.
Ditto plate, (S. G. 2.76)	1.573	C.
Ditto bottle	1.582	Br.

N. B. It is probable that the more refractive specimens of this list are low flint glasses, containing lead.

Spermaceti, cold	1.503	B. Y.
	1.535	W.
Oil of pimento	1.503	B. Y.
	1.507	Br.
	1.510	B.Y.
Starch (dry)	1.504	B. Y.
Muriate of antimony, dry	1.504	B. Y.
Ditto, two days exposed	1.613	B. Y.
Oil of amber	1.505	W.
	1.507	B. Y.
Birdlime	1.506	B. Y.
Oil of sweet fennel seed	1.506	Br.
	1.507	B. Y.
Balsam of Copaiba	1.507	W.
	1.514 1.516	B. Y.
	1.528	Br.
Stilbite	1.508	Br.
Oil of cummin	1.508	Br.
	1.578	B. Y.
Scammony	1.510	B. Y.
Oil of mace	1.512 1.526	B. Y.
Gum Arabic	1.512	Br.
Ditto (not quite dry)	1.513	B. Y.
Ditto	1.514	W.
Human cuticle	1.514 1.517	W.
Nitre, greatest index	1.514	Br.
Ditto, least	1.335	Br.
Ditto	1.524	C.
"Niter" (?) S. G. 1.9	1.524	N.
Dantzic vitriol (sulphate of iron)	1.515	N.
Nadelstein from Faroe	1.5153	Br.
Mesotype, least index	1.516	Br.
Ditto, greatest	1.522	Br.
Sulphate of zinc, ordinary refraction	1.517	Br.
Myrrh	1.517	B. Y.
	1.524	Br.
Tartaric acid, least refraction	1.518	Br.
Ditto, greatest	1.529	Br.
	1.575	Br.
Gum dragon (Tragacanth)	1.520	Br.
	1.66	W.
Glass of borax 1, silex 2	1.522	Br.
Gum lac, or Shell lac	1.52+	W.
	1.525	Br.
	1.528	B. Y.
Oil of sassafras	1.522	B.Y.
	1.532	Br.
	1.536	W.
	1.544	Eul.
Caoutchouc	1.524	W.
	1.534	Br.
	1.557	B. Y.
Selenite	1.525	W.
Ditto, greatest refraction	1.536	Br.
"A selenites, S. G. 2.252"	1.488	N.
Citric acid	1.527	Br.
Leucite	1.527	Br.
Canada balsam	1.528	W.
	1.532	B.Y.
	1.549	Br.
Balsam of Gilead	1.529	B. Y.
Crystalline of ox (dried) and of a fish	1.530	W.
Pitch	1.531	W.
	1.581	B. Y.
	1.586	Br.
	1.588	B. Y.
Sulphate of copper, least refraction	1.531	Br.
Ditto ditto, greatest	1.552	Br.
Olibanum	1.532	B. Y.
	1.544	Br.
Brazil pebble, (S. G. 2.62)	1.532	C.
Glass of phosphorus (fused phosphoric acid)	1.532	Br.
Solid phosphoric acid	1.544	Br.
Glass of borax (fused borax)	1.532	Br.
Manna	1.533	B. Y.
Ditto, burned	1.547 1.565	B. Y.
Arragonite, extraordinary index	1.5348	M.
Ditto, ordinary	1.6931	M.
Elemi	1.535	W.
	1.547	Br.
	1.550	B. Y.
Mastic	1.535	W.
	1.539	B. Y.
	1.560	Br.
Arseniate of potash	1.535	W.
Gum anime	1.535	W.
	1.546	B. Y.
Copal	1.535	W.
	1.549	Br.
	1.553	B.Y.
Oil of cloves	1.535	W.
	1.539	B. Y.
White sugar	1.535	W.
Ditto	1.541	B. Y.
Ditto (melted)	1.545	B. Y.
Ditto (after melting)	1.555	Br.
Felspar	1.536	Br.
Oil of cashew nut	1.536	B. Y.
Oil of aniseed	1.536	B. Y.
	1.601	Br.
Mellite	1.538	Br.
Ditto	1.556	Br.
Gum juniper	1.538	Br.
	1.541	B. Y.
Carbonate of barytes, least refraction	1.540	Br.
Box-wood	1.542	W.
Colophony	1.543	W.
Apophyllite, the variety which exhibits white and black rings (*Leucocyclite*)	1.5431	He.
Carbonate of strontia, least refraction	1.543	Br.
Ditto ditto greatest	1.700	Br.
Dichroite (iolite)	1.544	Br.
Petroleum	1.544	B. Y.
Sal gemmæ, S. G. 2.143 (rock salt)	1.545	N.
Ditto (rock salt)	1.557	Br.
Chio turpentine	1.545	B. Y.
	1.557	Br.
Gum sagapenum	1.545	B. Y.
Turpentine	1.545	B. Y.
Burgundy pitch	1.546	B. Y.
	1.560	Br.
Gum thus	1.546	B.Y.
	1.554	Br.
Oil of tobacco	1.547	Br.
Rock crystal	1.547	W.
Quartz, ordinary refractive index	1.5484	M.
Ditto, extraordinary	1.5582	M.
Amethyst	1.562	W.
Rock crystal (double)	1.562	Br.
Crystal of the rock (S. G. 2.65)	1.563	N.
Rock crystal	1.568 1.575	C.

Light.

greatest in the chemical scale, such multiplication will depress the rank of the former, and exalt that of the latter, so as to separate them entirely from the proximity they now hold. A distinction, too, will require to be regarded between compound and simple atoms. But as these considerations are peculiar to the system of emission, we shall not prosecute them farther in detail

The dispersive powers of bodies afford another very interesting and distinctive character. Of these, Dr. Brewster, in his Treatise on *New Philosophical Instruments*, has given the following extensive table, almost entirely from his own observation.

1120. Table of Dispersive Powers.

TABLE OF DISPERSIVE POWERS.

Column 1 contains the name of the medium; column 2 the value of the function $\frac{\delta\mu}{\mu-1}$; column 3, that of $\mu\,\delta$ simply, $\delta\mu$ being the difference of refractive indices of extreme red and violet rays.

Dispersive Powers.	$\frac{\delta\mu}{\mu-1}$	$\delta\mu$.	Author.	Dispersive Powers.	$\frac{\delta\mu}{\mu-1}$	$\delta\mu$.	Author.
Chrom. lead, greatest estimated	0.400	0.770	B.	Oil brick	0.046	0.021	B.
Ditto greatest exceeds	0.296	0.570	B.	Flint glass, (Boscov. lowest)	0.0457		B.
Realgar, melted, different kind	0.267	0.394	B.	Nitric acid	0.045	0.019	B.
Chrom. lead, least refraction	0.262	0.388	B.	Oil lavender	0.045	0.021	B.
Realgar melted	0.255	0.374	B.	Balsam of sulphur	0.045	0.023	B.
Oil cassia	0.139	0.089	B.	Tortoise shell	0.045	0.027	B.
Sulphur after fusion	0.130	0.149	B.	Horn	0.045	0.025	B.
Phosphorus	0.128	0.156	B.	Canada balsam	0.045	0.024	B.
Balsam Tolu	0.103	0.065	B.	Oil marjorum	0.045	0.022	B.
Balsam Peru	0.093	0.058	B.	Gum olibanum	0.045	0.024	B.
Carb. lead, greatest	+0.091	+0.091	B.	Nitrous acid (?)	0.044	0.018	B.
Barbadoes aloes	0.085	0.058	B.	Cajeput oil	0.044	0.021	B.
Oil aniseed	0.074	0.044	B.	Oil hyssop	0.044	0.022	B.
Balsam styrax	0.069	0.039	B.	Oil rhodium	0.044	0.022	B.
Guiacum	0.066	0.041	B.	Pink coloured glass	0.044	0.025	B.
Carb. lead, least refraction	0.066	0.056	B.	Oil savine	0.044	0.021	B.
Oil cummin	0.065	0.033	B.	Oil poppy	0.044	0.020	B.
Gum ammoniac	0.063	0.037	B.	Jargon, greatest refraction	0.044	0.045	B.
Oil Barbadoes tar	0.062	0.032	B.	Mur. acid	0.043	0.016	B.
Oil cloves	0.062	0.033	B.	Copal	0.043	0.024	B.
Green glass	0.061	0.037	B.	Nut oil	0.043	0.022	B.
Sulphate lead	0.060	0.056	B.	Burgundy pitch	0.043	0.024	B.
Deep red glass	0.060	0.044	B.	Oil turpentine	0.042	0.020	B.
Oil sassafras	0.060	0.032	B.	Oil rosemary	0.042	0.020	B.
Opal coloured glass	0.060	0.038	B.	Felspar	0.042	0.022	B.
Resin	0.057	0.032	B.	Glue	0.041	0.022	B.
Oil sweet fennel seed	0.055	0.028	B.	Balsam capivi	0.041	0.021	B.
Oil spearmint	0.054	0.026	B.	Oil nutmeg	0.041	0.021	B.
Orange glass	0.053	0.042	B.	Stilbite	0.041	0.021	B.
Rock salt	0.053	0.029	B.	Amber	0.041	0.023	B.
Flint glass, (Boscov. greatest)	0.0527		Bos.	Oil peppermint	0.040	0.019	B.
Caoutchouc	0.052	0.028	B.	Spinelle	0.040	0.031	B.
Oil pimento	0.052	0.026	B.	Carb. lime, greatest refraction	0.040	0.027	B.
Flint glass	0.052	0.032	B.	Oil rape seed	0.040	0.019	B.
Deep purple glass	0.051	0.031	B.	Bottle glass	0.040	0.023	B.
Oil Angelica	0.051	0.025	B.	Gum elemi	0.039	0.021	B.
Oil thyme	0.050	0.024	B.	Sul. iron	0.039	0.019	B.
Oil fen (? fenu) greek	0.050	0.024	B.	Diamond	0.038	0.056	B.
Oil wormwood	0.049	0.022	B.	Oil olives	0.038	0.018	B.
Oil pennyroyal	0.049	0.024	B.	Gum mastic	0.038	0.022	B.
Oil carraway	0.049	0.024	B.	White of egg	0.037	0.013	B.
Oil dill seed	0.049	0.023	B.	Oil rhue	0.037	0.016	B.
Oil bergamot	0.049	0.023	B.	Gum myrrh	0.037	0.020	B.
Flint glass	0.048	0.029	B.	Beryl	0.037	0.022	B.
Chio turpentine	0.048	0.028	B.	Obsidian	0.037	0.018	B.
Gum thus	0.048	0.028	B.	Ether	0.037	0.012	B.
Flint glass	0.048	0.028	B.	Selenite	0.037	0.020	B.
Oil lemon	0.048	0.023	B.	Alum	0.036	0.017	B.
Oil juniper	0.047	0.022	B.	Oil castor	0.036	0.018	B.
Oil chamomile	0.046	0.021	B.	Sulphur copper	0.036	0.019	B.
Gum juniper	0.046	0.025	B.	Crown glass, very green	0.036	0.020	B.
Carb. strontia, greatest refrac.	0.046	0.032	B	Gum Arabic	0.036	0.018	B.

Use of the polarizing angle as a physical character.

Action of crystallized surfaces on reflected light.

of cases to decide between two substances, which might be otherwise confounded together, and inasmuch as it can be measured on any single surface sufficiently polished to give a regular reflexion, thus enabling us to apply this character to minute fragments, or to specimens set as jewels, or otherwise too precious to be sacrificed; to opaque bodies, and to a variety of other cases where a direct measure of the refraction would be impracticable. It has not escaped the acute and careful observation of Dr. Brewster, that the polarizing angle on the surfaces of crystallized media is not absolutely the same in all planes of incidence; and the deviation, though excessively small when the natural reflexion is used, becomes very sensible, and even enormous, when the reflexion is weakened by covering the surface with a cement of a refraction approaching that of the medium, so as to allow only those rays to reach the eye which have penetrated, as it were, to some minute depth, and undergone some part of the action of the crystal *as such*. The point is among the most curious and interesting in the doctrine of reflexion, and we regret that our limits, as well as the obscurity still hanging over it, and which it will require much elaborate research to dissipate, prevent our devoting a section to it, but we must be content to refer the reader to an excellent paper on the subject by that Philosopher, *Philosophical Transactions*, 1819.

1124. Table of angles between the optic axes of crystals.

The angles included between the optic axes of biaxal crystals is a physical character of the first rank, both on account of its distinctness, its extent of range, (indifferently over the whole quadrant,) and its immediate and intimate connection with the state in which the molecules of the crystals subsist, and what may, loosely speaking, be termed their structure. It is, however, a character by no means easily determined: both axes rarely lying within one field of view, capable of being examined through natural surfaces, and requiring, in almost all cases, the production of artificial sections; at least, this is the only safe way for observations of the tints, for the angles at which, in a thin parallel plate, the several successive orders of colours are produced in situations remote from the axes, are for the most part far too vague to lead to any accurate conclusion as to the position of these lines within the plate, not to speak of the sources of fallacy highly coloured, or dichroite, crystals obviously present. With these considerations before us, we cannot but be struck with surprise and admiration at the unwearied assiduity, which could produce, almost unassisted, a table of results so extensive and so valuable as the following.

Table of the Inclinations of the Optic Axes in various Crystals.

I. UNIAXAL CRYSTALS. *Inclination* = 0.

Negative Class.

Carbonate of lime, (Iceland spar.)
Carbonate of lime and magnesia, (bitter spar.)
Carbonate of lime and iron, (brown spar.)
Tourmaline.
Rubellite.

Corundum.
Sapphire,
Ruby.
Emerald.
Beryl.
Apatite.

Idocrase, (Vesuvian.)
Wernerite.
Mica from Kariat.
Phosphate of lead.
Phosphato-arseniate of lead.
Hydrate of strontia.

Arseniate of potash.
Muriate of lime.
Muriate of strontia.
Subphosphate of potash.
Sulphate of nickel and copper.

Positive Class.

Zircon.
Quartz.
Oxide of iron.

Tungstate of zinc.
Titanite.
Boracite.

Apophyllite.
Sulphate of potash and iron.
Superacetate of copper and lime.

Hydrate of magnesia.
Ice.

Unclassed.

Hyposulphate of lime.

Oxysulphate of iron.

II. BIAXAL CRYSTALS.

Names of crystals.	Character of the principal axis according to Dr. Brewster's system.	Inclination of optic axes.	Names of crystals.	Character of the principal axis according to Dr. Brewster's system.	Inclination of optic axes.
Sulphate of nickel, certain specimens ..	+	3° 0′	Mica	–	45° 0′
Carbonate of lead	–	5 15	Lepidolite	–	45 0
Sulphato-carbonate of lead	–	——	Benzoate of ammonia	+	45 8
Carbonate of strontia	–	6 56	Sulphate of magnesia and soda	..	46 49
Carbonate of baryta	–	——	Sulphate of ammonia	+	49 42
Nitrate of potash	–	5 20	Brazilian topaz (Brewster and Biot)	..	49 or 50°
Mica, certain specimens	–	6 0	Sugar	–	50° 0′
Talc	–	7 24	Sulphate of strontia	+	50 0
Mother of pearl....................	–	11 28	Muriosulphate of magnesia and iron	–	51 16
Hydrate of baryta	–	13 18	Sulphate of ammonia and magnesia..	+	51 22
Mica, certain specimens	–	14 0	Phosphate of soda	–	55 20
Arragonite..........................	–	18 18	Comptonite...	+	56 6
Prussiate of potash (? Ferrocyanate) ..	+	19 24	Sulphate of lime	+	60 0
Mica, certain specimens	..	25 0	Oxynitrate of silver	+	62 16
Cymophane	+	27 51	Iolite.......................... ..	–	62 50
Anhydrite	+	28 7	Felspar	–	63 0
Borax	+	28 42	Topaz (Aberdeenshire)...........	+	65 0
Mica, various specimens examined by M. Biot	..	30 0	Sulphate of potash	+	67 0
	..	31 0	Carbonate of soda	–	70 1
	..	32 0	Acetate of lead..................	–	70 25
	..	34 0	Citric acid.	+	70 29
	..	37 0	Tartrate of potash................	–	71 20
Biaxal apophyllite..................	–	35 8	Tartaric acid	–	79 0
Sulphate of magnesia	–	37 24	Tartrate of potash and soda........	+	80 0
Sulphate of barytes	+	37 42	Carbonate of potash	..	80 30
Spermaceti (about)	+	37 40	Cyanite..........................	+	81 48
Tineal (native borax)	–	38 48	Chlorate of potash	..	82 0
Nitrate of zinc (estimated)	..	40 0	Epidote, about	..	84 19
Stilbite	+	41 42	Muriate of copper	..	84 30
Sulphate of nickel	+	42 4	Peridot	..	87 56
Carbonate of ammonia..............	–	43 24	Crystallized Cheltenham salts	..	88 14
Sulphate of zinc	–	44 28	Succinic acid, estimated at about ..	..	90 0
Anhydrite (examined by Biot)........	..	44 41	Sulphate of iron, about	..	90 0

Light.

Polarizing powers considered as a physical character of media.

admit of being determined with sufficient precision, in such very imperfect specimens as are usually subjected to examination for the purpose of identification, and a much better course is to make the tint developed at a perpendicular incidence, by a plate of given thickness in a direction at right angles to both the optic axes, the object of determination. This tint (which we shall term the equatorial tint) may be derived immediately from observations of tints at any angle, by the formula

$$N = \frac{n}{t} \cdot \frac{\cos \rho}{\sin \theta \,.\, \sin \theta'},$$

where N is the tint in question, numerically expressed as usual, and where n is the tint, (also similarly expressed) developed at an angle of incidence whose corresponding angle of refraction is ρ, on a plate whose thickness is t, (expressed in English inches and decimals) and where θ, θ' are the angles made by the ray in traversing the plate with the two axes. This value of N is the same with $\frac{1}{h}$ in the equation of Art. 907. The following list of a very few substances will suffice to show the great range the value of N admits, and its consequent utility as a physical character, considerations which we hope will induce observers to extend the list itself, as well as to give it all possible exactness.

UNIAXAL CRYSTALS.

	For mean yellow rays.	
	$N=$	$h=\frac{1}{N}$
Iceland spar	35801	0.000028
Hydrate of strontia (assuming $\mu = 1.5$)	1246	0.000802
Tourmaline	851	0.001175
Hyposulphate of lime	470	0.002129
Quartz	312	0.003024
Leucocyclite (uniaxal apophyllite, 1st variety)	109	0.009150
Camphor	101	0.009856
Vesuvian	41	0.024170
Uniaxal apophyllite, 2d variety	33	0.030374
Ditto, 3d variety	3	0.366620

BIAXAL CRYSTALS.

	For mean yellow rays.	
	$N=$	$h=\frac{1}{N}$
Nitre	7400	0.000135
Anhydrite (angle between axes = 43° 48′)	1900	0.000526
Mica (angle between axes = 45°)	1307	0.000765
Sulphate of baryta	521	0.001920
Heulandite (white;—angle between axes = 54° 17′)	249	0.004021

1127. Use of polarized light in detecting complex structures.

But the phenomena of refraction, reflexion, and polarization, may not only be applied by the aid of these and similar tables of registered results, to the examination and identification of substances in the gross, they are also of use in detecting peculiarities of structure in individual specimens, or in certain species which would otherwise escape observation. The singular structure of amethyst has been already explained, and a variety of cases of hemitropism might be noticed, in which the juxtaposition of the parts is rendered evident by the test of polarized light. Of these, however, by far the most curious and interesting are those in which the juxtaposed parts combine to form a regular whole, and to produce a species of pseudo-crystal, built up as it were of several individuals, arranged with a regard to symmetry, and forming a structure of more or less complication. Such instances have been more particularly noticed in nitre, arragonite, topaz, apophyllite, sulphate of potash, analcime, harmotome, &c.

1128. Compound crystals of nitre. Arragonite.

The usual form of the crystals of nitre, when large and well developed, is the regular hexagonal prism; but a section of this, cut at right angles to the axis, is very commonly found to consist of two or more portions, in which the optic meridians are 60° inclined to each other; but the plane of division often intersects one of the lateral faces of the prism, without any visible external mark of a breach of continuity, so that but for the test of polarized light, the macled structure would never be discerned. The phenomena of arragonite, in this respect, are very similar to those of nitre.

1129. Topaz.

If a plate of Brazilian topaz, cut at right angles to the axis of the rhombic prism in which it crystallizes, be examined by polarized light, it will occasionally be found to consist of a central rhomb, surrounded by a border in which the optic meridians of the alternate sides are inclined at $\frac{1}{4}$ of a right angle to that of the central compartment, and $\frac{1}{2}$ a right angle to each other. In consequence, when such a rhombic plate is held with its long diagonal in the plane of primitive polarization, two opposite sides of the border appear bright, the other two black, and the central compartment of intermediate brightness. Such specimens often exhibit the phenomena of dichroism in the central compartment, while the border is colourless in all positions.

1130. Tesselite. Fig. 223.

But it is in the apophyllite of the variety named by Dr. Brewster, Tesselite, that this enclosure of one crystal in a case as it were of another, is exhibited in the most regular and extraordinary manner. In one of the varieties of this singular body, whose form is the right rectangular prism with flat summits, slices taken off from either summit were found by him to be of uniform structure; but, when these were detached, every subsequent slice was

Newton's theory of the colours of natural bodies. nent importance. Among these there is certainly none more entitled to consideration than the phenomena of colour, as exhibited by natural objects, which strike us wherever we turn our eyes, and it is impossible to pass in total silence the theory devised by Newton to account for them; a theory of extraordinary boldness and subtilty, in which great difficulties are eluded by elegant refinements, and the appeal to our ignorance on some points is so dexterously backed by the weight of our knowledge on others, as to silence, if not refute, objections which at first sight appear conclusive against it. The postulates on which this theory rests are essentially as follows:

1135. Postulates. 1. All bodies are porous; the pores or intervals vacant of ponderable matter, occupying a very much larger portion of the whole space filled by the body, than the solid particles of which it essentially consists.

1136. 2. These solid particles have a certain size (and perhaps figure) essential to them as particles of that particular medium, and which cannot be changed by any mechanical action, or by any means not involving a change in the chemical nature or condition of the medium. They are, in short, the ultimate *atoms*; to break which, is to destroy their essence, and resolve them into other forms of matter, having other properties.

1137. 3. These atoms are perfectly transparent, and equally permeable to light of all refrangibilities, which, having once passed their surfaces, is in the act of pursuing its course through their substances.

Newton, indeed, makes his atoms only "in some measure transparent." But he never refers to this limitation, and his theory depends essentially on their *perfect* transparency, as is indeed obvious from his account of opacity, which is contained in the next postulate.

1138. 4. *Opacity in natural bodies arises from the multitude of reflexions caused in their internal parts.*

Cause of opacity. It is obvious, therefore, that unless we admit a cause of opacity in *atoms* different from that which, on this hypothesis, causes it in their aggregates constituting natural bodies, the former cannot be otherwise than absolutely pellucid, since no reflexions can take place where there are no intervals, and no change of medium. Of the sufficiency of this cause, either in natural bodies or atoms, however, we confess there does appear to us some room for doubt, as it seems difficult so to conceive these internal reflexions, that the rays subjected to them shall be *all* and *for ever* retained, entangled as it were, and running their rounds from atom to atom, without a possibility of reaching the surface and escaping; which, were they to do, it is evident that every body so constituted, receiving a beam of light, would in fact only disperse it in all directions in the manner of a self luminous one.

1139. Origin of natural colours. 5. *The colours of natural bodies are the colours of thin plates, produced by the same cause which produces them in thin laminæ of air, glass, &c.* viz. the *interval* between the anterior and posterior surfaces of the atoms, which, when an odd multiple of half the length of a fit of easy reflexion and transmission for any coloured ray moving within the medium, obstructs its penetration of the second surface, and when an even, ensures it, (see Art. 655.) The *thickness*, therefore, of the atoms of a medium, and of the interstices between them, determines the colour they shall reflect and transmit at a perpendicular incidence. Thus, if the molecules and interstices be less in size than the interval at which total transmission takes places, or less than that which corresponds to the edge of the central black spot in the reflected rings, a medium made up of such atoms and interstices will be perfectly transparent. If greater, it will reflect the colour corresponding to its thickness.

1140. Objections. It may be objected to this, that all natural colours do not of necessity find a place in the scale of tints of thin plates, even those of bodies whose chemical composition is uniform; but to this we may answer, that the colours reflected from the first layer only of molecules next the surface ought to be *pure* tints, those from lower layers having to make their way to the eye through the upper strata, and thus undergoing other analyses, by transmissions and reflexions among the incumbent atoms. Besides which, whatever *shape* we attribute to the atoms, it is impossible that all rays shall penetrate them so as to traverse the same thickness of them, unless we regard them as mere *laminæ* without angles or edges, and of enormous refractive power.* The same answer must be made to the objection, equally obvious, that the transmitted tint ought to be in all cases complementary to the reflected one, and that therefore cases like that of leaf gold, opalescent glass, and infusion of *lignum nephriticum*, all which reflect one tint and transmit another, but in all which this condition is violated, form exceptions to the theory. But, in reality, the transmitted rays have traversed the whole thickness of the medium, and have therefore undergone, many more times, the action of its atoms, than those reflected, especially those near the first surface, to which the brighter part of the reflected colour is due.

1141. Apparent exceptions considered. The infusion of lignum nephriticum is a very singular case, and its peculiar properties have been explained by Dr. Young, on the supposition of minute particles of definite magnitude suspended in it. Though very transparent, it yet *reflects* a bluish green colour, while the light transmitted is yellow or wine-coloured, in this respect offering almost the exact converse of leaf gold. It is, however, no doubt a case of opalescence, and is exactly imitated by certain yellow glasses, in which a very visible thin film of opalescent matter near the surface reflects to the eye a bluish green tint, while yet the colour transmitted has the yellow tint belonging to the glass. The reflexion proceeds from particles which have nothing to do with the transmitted light.

1142. Case of transparent coloured media. But, in fact, the objection (as appears to us) is not yet fully answered. Transparent coloured media (*clear* liquids in which no floating particles exist,) have *no* reflected colour. When examined by pouring them into an opaque vessel, blackened internally and filled to the brim, and when the colourless reflexion from their upper surface is destroyed by reflexion in an opposite plane at the polarizing angle, it is seen at once that no light is reflected from within the medium, either near the surface, or at greater depths; and if this mode of examination be regarded as objectionable, as perhaps destroying the internal as well as external reflexion, it is equally satisfactory to observe, that the image of a white object reflected from the surface of a fluid in a black opaque vessel is always purely white, whatever be the colour of the reflecting fluid. We are not aware that the objection so put has been sufficiently considered, or even propounded. To us its weight appears considerable, and we cannot but believe that some other cause besides mere internal reflexions must interfere to prevent the complementary colour from reaching the eye; and that absorption, with its kindred phenomenon, or rather its extreme case, opacity, is not satisfactorily accounted for in this theory, but must rather be admitted as (at present,) an ultimate fact, of which the cause is yet to seek.

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* Newton appears to have been fully aware of the necessity of taking this into consideration. Prop. vii. book ii. *Opt. versus finem.*

1143. True and false colours.

If this be granted, the colours of all bodies may be distinguished into *true*, viz., those which arise from rays which have actually entered their substance and undergone their absorptive action, (as the colours of powders of transparent coloured media, cinnabar, red lead, Prussian blue, those of flowers, &c.,) and *false*, or *superficial*, or those which originate obviously in the law of interference; thus, the variable colours of feathers, insects' wings, striated surfaces, oxidated steel, and a variety of cases to which the Newtonian doctrine strictly applies, for there is no denying that cases of colour, not *merely* superficial, do occur, in which the Newtonian doctrine, to say the least, is highly probable. To instance one or two only. If a few drops of an extremely weak solution of nitrate of silver be added to a very dilute solution of hyposulphite of lime, a precipitate is formed of an opalescent whiteness and extreme tenuity. If more of the nitrate be added, the precipitate increases in weight and aggregation, and at the same time changes its colour, becoming first yellow, then yellow brown, then a rich orange brown, then a purplish brown, and, finally, a deep brown black. The precipitate, meanwhile, continually acquires density, and, finally, sinks rapidly to the bottom. It is impossible, in this series, not to trace the tints of the first order of reflected rings, produced by the thickening of the minute particles in the act of aggregation, but equally impossible not to recognise the agency of a cause totally different, acting to increase the opacity of the compound by an absorptive action far superior to, and independent of, the action of the particles as thin plates. The phenomena of *Hematine*, described by Chevreul and cited by Dr. Brewster, (*Encyc. Edin. Optics*, p. 623; see also Biot, *Traité de Phys.* tom iv. p. 134, there referred to,) afford too close an approximation to the series of tints of the second order not to authorize a presumption that the Newtonian theory may apply to this case also. The diffused light and blue colour of the clear sky, affords another very satisfactory instance. This blue is, no doubt, a blue of the first order, reflected from minute aqueous particles in the air. The proof is, that at 74° distance from the sun, it is *completely polarized* in a plane passing through the sun's centre.

Cases in which Newton's theory applies.

1144. Another objection. Answered.

Another objection, no less obvious, to the Newtonian doctrine, has been successfully answered by Newton himself. A change of obliquity of incidence, it may be urged, should cause a change of colour, as a plate of given thickness reflects a different tint at oblique and perpendicular incidences. But this variation is less, the greater the refractive power of the medium; and as the refractive power increases with the density, that of the dense ultimate atoms of bodies must be exceeding great, so that the tint reflected from them will vary little with a change of incidence, (art. 669.) The colours of oxidated steel afford an excellent case in point. The refractive power of this oxide, though great, (2.1), is, doubtless, not to be compared with that of the ultimate atoms of bodies, yet the tints on the surface of blued steel vary but little with a change of obliquity. We may add, too, that the colour exhibited by any body of sensible magnitude, is in reality an average of the colours reflected from all its molecules at all possible incidences, so that no change of incidence ought to be expected to affect it.

1145. Newton's ideas of the size of the particles of bodies.

Of the extreme tenuity of the ultimate molecules of bodies, Newton seems to have had but an inadequate idea, as he supposed that they might be seen through microscopes magnifying three or four thousand times.* We have viewed an object *without utter indistinctness*, through a microscope by Amici, magnifying upwards of three thousand times in linear measure, and had no suspicion that the object seen was even approaching to resolution into its primitive molecules. But it should rather seem that Newton regarded his colorific molecules as divisible *groupes* of atoms of a yet more delicate kind, and yet more dense, and these again as still further resolvable till the last stage of indivisibility be reached. M. Biot has given a striking, and, we may almost term it, picturesque account of this doctrine, in his *Traité de Physique*.

§ XV. *Of the Calorific and Chemical Rays of the Solar Spectrum.*

1146.

It has long been a matter of everyday observation, that solar light exercises a peculiar influence in altering the colours of bodies exposed to it, either by deepening or discharging them, even when totally secluded from air, and that various metallic salts and oxides, especially those of silver, are speedily blackened and reduced when freely exposed to direct sunshine, or even to the ordinary light of a bright day. Whether these effects were owing to the heat of the rays, or to some other cause, remained long uninquired. The first step was

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* The passage, however, is in the highest tone of a refined philosophy, and, independent of its theoretic bearings, we extract it, as indicating a scrutinizing spirit of observation far beyond the age he lived in.

"In these descriptions I have been the more particular, because it is not impossible but that microscopes may at length be improved to the discovery of the particles of bodies on which their colours depend, if they are not already in some measure arrived to that degree of perfection. For if those instruments are or can be so far improved as with sufficient distinctness to represent objects five or six hundred times bigger than at a foot distance they appear to our naked eyes, I should hope that we might be able to discover some of the greatest of those corpuscles. And by one that would magnify three or four thousand times perhaps they might all be discovered, but those which produce blackness. In the mean while I see nothing material in this discourse that may rationally be doubted of, excepting this position: That transparent corpuscles of the same thickness and density with a plate, do exhibit the same colour. And this I would have understood not without some latitude, as well because those corpuscles may be of irregular figures, and many rays must be obliquely incident on them, and so have a shorter way through them than the length of their diameters, as because the straitness of the medium put in on all sides within such corpuscles may a little alter its motions or other qualities on which the reflection depends. But yet I cannot much suspect the last, because I have observed of some small plates of Muscovy glass which were of an even thickness, that through a microscope they have appeared of the same colour at their edges and corners where the included medium was terminated, which they appeared of in other places. However, it will add much to our satisfaction, if those corpuscles can be discovered with microscopes; which if we shall at length attain to, I fear it will be the utmost improvement of this sense. For it seems impossible to see the more secret and noble works of nature within the corpuscles, by reason of their transparency."

Discoveries of Scheele. Sir W. Herschel.

Ritter.

made by Scheele, who ascertained that muriate of silver is much more powerfully blackened in the violet rays than in any other part of the spectrum. (*Traité de l'Air et du Feu*, § 66.) The experiments of Sir W. Herschel, on the heating power of the several prismatic rays, on the other hand, which appeared in 1800, showed satisfactorily that the more refrangible rays possess very little heating power, the calorific effect being at its maximum for the extreme red rays, and even extending considerably beyond the limits of the spectrum in that direction. This remarkable discovery, which established the independence of the heating and illuminating effects of the solar rays, led Professor Ritter, of Jena, in 1801, to examine whether a similar extension beyond the limits of the visible spectrum might not also have place in the chemical or deoxidating rays, and on exposing muriate of silver in various points within and without the spectrum, he found the maximum of effect to lie beyond the visible violet rays, the action being less in the violet itself, still less in the blue, and diminishing with great rapidity as he proceeded towards the less refrangible end. Dr. Wollaston independently arrived at the same conclusion.

1147. Calorific, luminous, and chemical rays.

The solar rays, then, possess at least three distinct powers: those of heating, illuminating, and effecting chemical combinations or decompositions, and these powers are distributed among the differently refrangible rays, in such a manner as to show their complete independence on each other. Later experiments have gone a certain way to add another power to the list—that of exciting magnetism. Without calling in question the accuracy of the observations which are directed to establish this point, we may be permitted to hope that further researches will, ere long, explain the causes of failure in those numerous cases where such effects have not been produced.

1148. All obey the same optical laws.

Chemical rays interfere like luminous ones.

The calorific rays appear, from experiments of Berard, to obey the laws of polarization and double refraction, like those of light. Those of interference could not be made without excessive difficulty. In the case of the chemical rays, the same difficulty is not experienced; and Dr. Young, and after him, by more delicate means, M. Arago, have satisfactorily demonstrated that these conform to the same laws of interference, whether polarized or otherwise, that are obeyed by the luminous rays similarly circumstanced. Thus, a set of fringes formed by the interference of two solar pencils with a common origin, being kept very steadily projected for a long time on one and the same part of a sheet of paper rubbed with muriate of silver, a series of black lines became traced on it, the intervals of which were smaller than those of the dark and luminous fringes formed by homogeneous violet light.

1149. Wollaston's observations on guiacum.

Dr. Wollaston having observed that gum guiacum is turned green by exposure to solar light in contact with air, took two specimens of paper coloured with a yellow solution of this gum in alcohol, and exposed one of them to air and sunshine, the other to air in the dark. The former was turned perceptibly green in five minutes, and the change was complete in a few hours, while the latter was no way discoloured after many months. He then concentrated the violet rays on paper so coloured, by a lens, and the change was speedily performed, while in the most luminous there was no change of colour, and, in the red rays, the green colour was not only not produced, but when induced by exposure to the violet, was again destroyed, and the original yellow colour restored. This seems, however, to have been merely an effect of the heat, as the warmth from the back of a heated silver spoon discharged the green colour just as effectually.

1150. Effect of light on purple glass.

Mr. Faraday has observed that glass tinged purple with manganese, has its hue much deepened by the passage of solar light through it, and that two portions of the same plate, one preserved in the dark, the other exposed freely, after some time differ materially in intensity of colour.

1151. Other effects of solar light.

The direct action of solar light, or, possibly, of its heat also, produces other chemical effects, such as the immediate combination of the elements of phosgen, the explosion of an atomic mixture of chlorine and hydrogen, and other phenomena, all indicative of powers resident in this wonderful agent, of which we have but a very imperfect notion at present. The green colour of plants, and the brilliant hues of flowers, depend entirely on it. Tansies which had grown in a coal pit, were found totally destitute either of colour or of their peculiar and powerful flavour, and the bleaching and sweetening of celery by the exclusion of light, is another familiar instance of the same cause. How far the differently coloured rays are concerned in these effects, has never yet been *accurately* investigated, though attempts have been made; but we hope, from the distinguished ability of an eminent individual who has recently taken up this most interesting inquiry, that our stock of knowledge will soon receive material accessions.

1152. We cannot close this Essay without an expression of regret, that the Memoir of Professor Airey, on the Spherical Aberration of the Eyepieces of Telescopes, just on the point of publication in the *Transactions of the Cambridge Philosophical Society*, reached us too late to allow of our attempting to condense its valuable contents, and we can only recommend it to the notice of our readers in lieu of, and in preference to, anything we could ourselves say on that subject. A similar expression of regret applies to the interesting "Theory of Systems of Rays," by Professor Hamilton of Dublin, a powerful and elegant piece of analysis, communicated to the Royal Irish Academy in 1824, and only now in the course of impression, but of which enough has reached us, by the kindness of its Author, to make us fully sensible of the benefit we might have derived from its perusal at an earlier period of our undertaking.

Slough, December 12, 1827. **J. F. W. HERSCHEL**

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ERRATA ET CORRIGENDA.

N B. The reader is requested to correct in advance the following Errata, and to strike out the passages here referred to

Page.	*Line.*	*Error.*	*Correction.*
✓ 341,	30,	existences,	existence.
do.	31,	more,	most.
347,	2,	line,	sine.
349,	26,	as the sun's surface,	at the sun's surface
389,	5 from bott.	$-\frac{y^2}{2\mu}\{$	$-\frac{y^2}{2\mu L}\{$
399,	47,	axis,	axes.
400,	15,	act,	art.
401,	15,	P E,	P C.
402,	30,	R, R O *p*,	P, P O *p*.
do.	35,	*p*,	Q.
410,	22 from bott.	*dele* " see *Micrometer*, in a subsequent part of this Article.'	
414,	44,	*dele* " by the writer of these pages."	
415,	3 from bott.	by water,	into water.
420,	30,	*spectra of distortion*,	subordinate spectra.
428,	17,	secondary,	second.
431,	33,	R *r*, V *v*,	R R′, V V′.
do.	36,	R N V,	R′ N V′.
434,	27,	from experiments,	from other experiments.
454,	28,	P B, P Q, or A B,	P B – P Q, or A B.
461,	11 from bott.	two vibrations,	two rectangular vibrations.
476.	14 from bott.	*dele* all that relates to the fringes on the wings of the *Papilio Idas*, being founded on a mistake.	
480,	32,	limits,	limit.
509,	38,	fails,	falls.
521,	1,	produce,	to produce.
524,	margin, Art. 925,	polarization,	depolarization.
528,	22,	positive class,	attractive class.
531,	16,	*add as follows:*—With respect to this third law, however, it must be confessed that it appears to require a stricter examination, as, if admitted in its full extent, it seems to controvert the fundamental principles of the doctrine of interference	
564,	19,	*dele* what is said about the nodal lines.	
560,	32 from bott.	*after* disprove it, *insert as follows:* Instead of the expression (*b*,) Art. 1073, we might otherwise assume $T = (Y \cdot \cos 2\varphi^2 + B \cdot \sin 2\varphi^2) \cdot (y \cdot \cos \nu^2 + b \cdot \sin \nu^2)$, and determining the coefficients accordingly, obtain another expression for the tint.	

within the last ten years been made upon the most powerful of the vegetable tribe in the *Materia Medica*, and from these it would seem that it is possible, in very many cases, to separate the active medical principle from the ligneous and inert matter by which it is accompanied, and to present it in a pure crystalline form. By this process two objects of considerable importance are attained: the one, that the woody matter which (as in the case of bark) frequently disordered the stomach, is got rid of: and the other that the uncertainty as to the strength of dose, which in vegetable substances varied greatly, is altogether obviated. There are also other minor advantages of portability, &c.; which are by no means unworthy of attention in a question of such extensive public importance.

History of Alchemy.

Chemistry, according to the definition we have given to it, is but a Science of very recent introduction: it can scarcely be said to have existed two hundred years. But it has been usual to connect its History with that of another Science, possessed of considerable similarity in many of its processes; though differing widely in the objects at which its professors aimed. Every labour of the Alchemist and all his ingenuity was directed towards one or other of the following objects: the transmutation of the baser metals into gold; or the preparation of an universal medicine, which should arrest the progress of all disorders incident to the human frame; and thus prolong the life of the successful adept to an indefinite period of duration. Of the labours of the Alchemists there are abundant records remaining. Numerous manuscripts yet exist in extensive Libraries, especially in those of Paris and Leyden, written in Arabic, in Greek, in Latin, as well as in the languages of modern Europe. Besides this, the Press poured forth its thousands of volumes of this description during the XVIth and XVIIth centuries: and, by way of offering some idea of the prolific industry of these authors, we may mention that Petrus Borellus has given a catalogue of more than four thousand such publications up to the year 1654. It is to be remarked, however, that in this catalogue he has admitted the names of many Alchemists whose works have never been published, and perhaps never committed to paper: but, on the other hand, the list might be greatly increased by names which he has omitted, or which had not appeared at the time of his publication.* The writings of the Alchemists, though not altogether unworthy of perusal, are of very various degrees of merit. In some we may trace the bold impostor, who came forward declaring that he possessed powers and secrets which he must have known that he had not; and who attempted to make a gain of the credulity of others, when, had he really been able to effect the *opus magnum*, far other evidences would have been brought forward than a mere appeal to the liberality of others to supply the fire of his furnaces. In others we find only the patient, mindless plodding of those who endeavoured to follow instructions of such studied obscurity, that at each successive failure the unhappy Alchemist only thought that he had misunderstood the directions of his master; and never suspected the knowledge or sincerity of the guide he was blindly following. In this crowd of writers there are, indeed, a few deserving higher estimation, men who worked industriously and described faithfully their attempts, their failures, and consequent disappointments. Had the labours of this class been guided by any thing like inductive reasoning, or had they even studied to vary the substances upon which they operated, as sedulously as they did to vary the mode of their operation and the forms of their apparatus, we might even now look back to their writings for experiments isolated, indeed, and devoid of order; but still valuable as recorded facts. Instead of this, however, the very best of them went on torturing the same vessel of quicksilver, with precisely the same operation fifty times repeated: and subjected the same portion of spirit of wine to three hundred consecutive distillations Can we wonder then that the latest Alchemist, as he rigidly persevered to walk in the steps of his predecessors, should in reality be as far from having any true Chemical knowledge of the constitution of nature as Geber or even Hermes himself. It would appear, further, that much as the Alchemists professed to reveal of their Arcana, each one was unwilling to put the rest of the world in full possession of any thing of value at which he might have arrived. This might in part arise from a desire which many of them obviously possessed of inducing a general belief in the superiority of their own individual attainments. Thus Roger Bacon, a man second to no one of his day in all that then constituted learning, and of consummate ability, yet when he describes (as we fully think he does describe) the preparation of gunpowder, names at once the *salis petræ et sulphuris*, but conceals the remaining ingredient, the *carbonum pulvere*, under the anagram of *luru mone cap urbre*.

We may smile at the pertinacity with which the Alchemist pursued his lengthy processes of cohobation and digestion, through wearisome days and sleepless nights, wasting his money and wearing out his vessels with perpetual fires: and, perhaps, it is lawful to express some little surprise that the repeated failure of his hopes, and the evidence of his own experimental facts, did not force upon him this obvious truth; that the thing he sought was impossible or impracticable. But in his defence be it said that he had abundance of attestation that others had actually succeeded in the process of transmutation; and the studied obscurity in which all the instructions of the most celebrated adepts were enveloped, might always leave him in doubt whether his failures were not chargeable to his own misapprehension. Besides, there were, in favour of the possibility of transmutation, some simple and well known experiments which had wonderfully the semblance of such an operation. Such, for instance, is the precipitation produced by dipping a polished iron rod into a solution of a salt of copper.

Many adepts professed to have obtained the secret of metallic transmutation, and, by the help of good legerdemain, some well attested instances of their successful operations are on record. Few, however, were like Paracelsus, bold enough to profess to have found out the *Elixir of Life*, the *Universal Medicine*. It is needless to say that these few gave rather an unfavourable attestation to their roguery or credulity, by submitting, like their neighbours, to the common lot of mortality. Yet even these were not quite without a reason in their folly; for, in the first place, the operations of Chemistry had, recently, so prepared some metallic bodies, as to render their effects little short of miraculous in arresting the progress of disease; therefore they might well hope to see still greater effects produced by further investigations. And, as to the question of the duration of life, there are some, even while we now write, who seem to think that "the disease of death" is one which, by a proper combination of circumstances, might be altogether avoided.

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* Upon the best estimate that we can form, the Alchemistical Authors amount to about one thousand; and their Treatises to about three times that number.

ALCHEMY is generally considered the parent of CHEMISTRY. We have shown, however, that the objects of the two Sciences differed considerably from each other: and we are inclined to believe that CHEMISTRY would have sprung into existence much about the time that it did so, even had ALCHEMY never been practised. That spirit of investigation, which spread its active energies throughout Europe early in the XVIIth century, must, we think, speedily have demanded and created for itself the exercise of those investigations which we now call Chemical. However, be this as it may, the Chemists found the instruments of the Alchemists ready fitted to their hands; they found also some useful facts recorded, though these were, in number, by no means equivalent to the labours, and the time, that had been expended in amassing them. At the dawn of Chemical Science, the wisest among the Alchemists, quitting their ancient chimerical pursuits, embarked in the legitimate processes of experimental Chemistry. Hence the one Science seems to have arisen out of the ashes of the other; and the Histories of Alchemy and Chemistry flow on in one continuous stream. There have, it is true, been at all times, and there did, very recently, if there do not now exist, in this Country, genuine disciples of the old Alchemical school, retaining processes and reasonings altogether distinct from those of modern Chemistry, but with these we have not time now to amuse ourselves.

History of Alchemy.

From these general remarks, we proceed to a very short outline of the History of these two Sciences. We could, indeed, with pleasure, enter upon the neglected reveries of the Alchemists as a matter of amusement; and many a choice and quaint passage could we adduce from their writings; but this would, we fear, be offering amusement without instruction; and, therefore, we shall pursue it only to a limited extent. With regard to the Chemists, it would be equally interesting and far more instructive were we to bring each in chronological review before us. Taking their published Works, we might, as it were, cause them to live over again, and observe the industry of one, the acute reasoning and well-directed research of another; or, with the aid of modern powers, we should frequently perceive how slight has been the interval between some ancient experiment and some important fact which remained to reward the more recent Chemist with a brilliant discovery. But even this project we must, in a great measure, abandon for the purpose of devoting all the space which can be allotted to us, to a condensed statement of those observed facts, and a description of those modes of experiment, an acquaintance with which constitutes Chemical Science.

If we look to the Alchemists for the early History of their own Science, we shall find that it is carried up to the most remote antiquity. Though the ancient Alchemical writers have said nothing satisfactory as to the origin of their craft, Borrichius, and later authors, who felt that many of the processes of the artificer were dependent upon Chemical agencies, thence inferred that they were the result of Chemical knowledge. On these grounds, Tubal Cain, the first artificer in iron and brass, has been considered the father of Metallurgic Chemistry. There is also a story in Vossius which was believed by Tertullian, that the knowledge of Chemical Principles was among the gifts bestowed by the Angels who were led from heaven by the beauty of the daughters of the earth. Others, more moderate, deem Noah the first Chemist, because he is said to have discovered the art of making wine. Ham, the son of Noah, and his descendants, to whom the Arts and Sciences seem to have been a heritage, are thus celebrated by some. Du Fresnoy, for instance, says, *Si Mezraim fils de Cham n'exerça pas lui-même la Chimie, l'on croit du moins qu'il la fit exercer par son fils aîné Thaut ou Athotis, nommé aussi Hermes ou Mercure, que devint Roi de Thebes. Cham porta donc,vraisemblablement, cette science en Egypte, ou du moins son fils Mezraim, et c'est delà que nous la voyons se rèpandre dans l'univers.*

Tubal Cain.

Noah.

Et sur ce que Noé a eu des enfans à l'âge de 500 *ans, je ne dirai pas comme a fait Vincent de Bauvais, que le sainte Patriarche a pratiqué lui-même la Chimie la plus parfaite, et qu'il a eu la Médecine universelle, qui est la partie la plus sublime de la Philosophie Hermétique: il suffit de la donner à Cham, ou à ses déscendans, qui la cultivèrent en Egypte, avec beaucoup d'autres sciences inconnues au reste de l'humanité. Et si l'on pouvait croire que l'ouvrage, rapporté dans les MSS. Grecs de cette science sous le nom d'Isis, fut de cette Princesse, on seroit assuré de l'antiquité de la Philosophie en Egypte, puisque elle étoit l'épouse d'Osiris, qui est le même que Mezraim: ainsi la pratique de la Science Hermètique paroît remonter à plus de* 25 *siècles avant l'Ere vulgaire. Mais je ne porte pas si loin ma prètention. Il suffit donc de la rapporter à* Hermes *ou* Mercure *surnommé* Trismegiste." (*Hist. de la Phil. Hermét.* p. 9.)

M. Dupin also asserts, that "several Jews have forged books which they have fathered upon the Patriarchs: such, for instance, as the book entitled The Generations and Creations of Adam. It was a common opinion among them, that Adam composed a treatise concerning the Philosopher's stone: and there is a book of Magic which is thus attributed to Cham, of which Cassius makes mention." (*Eccles. Hist.* fol. ed. p. 27.)

Hermes Trismegistus.

We advance then to the second *Hermes*, surnamed *Trismegistus:* a personage who has always been regarded with peculiar veneration by Alchemists of every subsequent Age. SIPHOAS, king of Thebes and Memphis, who lived about two thousand years (his reign commenced, according to Du Fresnoy, B. C. 1996) before the Christian æra, was celebrated for great attainments in the Arts and Sciences; known to the Greeks by the name of Hermes (Mercurius) Trismegistus, and generally considered the founder of Alchemical Science, which thence has been frequently termed the Hermetic Art. Tertullian styles him *Physicorum Magister.* Some Treatises, attributed to him, have been published, and more yet remain in manuscript; but it is the general belief that not one of these is the genuine work of Siphoas.

Moses.

From Egypt, then, it is really probable that the Hermetic Philosophy might pass to the Israelites, and Moses has been claimed as an adept, because he is recorded to have been skilled in all the learning of the

Egyptians. The Greeks also derived their knowledge from the same source; and, passing by the names of Sophar the Persian, and Ostanes the Mede, who lived in the time of Xerxes, we arrive at Democritus the Greek Philosopher, who lived in the Vth century before Christ. There are several manuscript copies of a Treatise in Greek, attributed to this author, which Treatise has been printed, together with an ancient Commentary by Synesius, Bishop of Ptolemais.

Of Comarius or Comanus, an Egyptian Priest, there is a MS. treatise on Alchemy in Greek. He lived about 50 B. C. and is said to have instructed Cleopatra in the Hermetic Science. There exist also Treatises which pretend to have been written by this queen, and the solution of a pearl to form a costly potion, is adduced as a proof of her Philosophical attainments.

Caligula.

The Hermetic Science had passed into Rome also. Pliny informs us (lib. xxxiii. cap. 4.) that Caligula attempted transmutation on a large scale: *et planè fecit aurum excellens, sed ita parvi ponderis, ut detrimentum sentiret.*

Some check was, at length, given to the pursuits of Alchemy in Egypt; for we are informed that Diocletian, A. D. 284, caused the Hermetic writings of the Egyptians to be collected and burned: supposing that it was by means of the gold thus fabricated, that they were enabled to procure supplies during their rebellions against his government. If any manuscripts of importance escaped from this search, it is probable that they subsequently perished with the thousands of others destroyed at the taking of Alexandria by the Saracens, under the Caliph Omar.

The Alchemic fire, however, if we may believe its Historians, still continued to burn steadily if not strongly: and the following series of writers is mentioned by various authors, as having left Treatises which yet exist.

Athenagoras, a Christian Philosopher, A. D. 176. *Du Parfait Amour*, printed at Paris, 1599 and 1612. Synesius, Bishop of Ptolemais, A. D. 410, left Greek MSS. on Alchemy, and his Commentary on Democritus is printed in *Fabricii Bibl. Græc.* tom. viii. Heliodorus, Bishop of Tricca in Thessaly, A. D. 405, printed in *Fabricii Bibl. Græca*, tom. vi. Zosymus of Alexandria, A. D. 410, numerous Treatises in MS. Archelaus, A. D. 415, MS. Pelagias, A. D. 420, MS. Olympiodorus, A. D. 430. MS. Theophrastus, A. D. 450. A Christian Philosopher, *De sacrâ et divinâ arte*, MS. Stephen of Alexandria, A. D. 630, MS. Pappus, a Christian Philosopher, A. D. 638, MS. Cosmus, a Monk, A. D. 650, MS.

Alchemy in Arabia.

Respecting the origin and progress of Chemistry in Arabia, the general belief is, that previous to the time of Mahomet, the Arabs entirely neglected the cultivation of Philosophy of every kind. "During the reign of their fourteen first Caliphs, *viz.* from A. D. 661 to A. D. 748, they were solely employed, like their ancestors, in preserving the purity of their language; in the study of the Koran; with the addition of some medicinal knowledge, which they found a matter of practical utility."

The contempt for every species of Science which the followers of Mahomet long retained, has been illustrated by the following well known anecdote, which is thus given by Du Fresnoy. "Amru, the Arabian General, having made himself master of Alexandria, (A. D. 640,) found in that celebrated city a Library well stored with numerous Philosophical writings. John Philoponus, an able commentator on Aristotle, was then a teacher in that city. He requested the Mohammedan General to grant him all the Philosophical works which might be found in the Library. Amru dare not take upon himself to make this present to Science. He therefore wrote for instructions from Omar, the second Caliph: but the answer which he received was fatal to the works and to Science. The Caliph remarked that if the writings were found contrary to the Koran, they must be destroyed, as being pernicious: but that if they were conformable to its dogmas, they became useless, as the Koran was all-sufficient. Thus none were preserved; all underwent one common fate and were destroyed. They were employed in heating the baths at Alexandria, and were more than six months in being consumed, though there were then more than 4000 baths in the city."

The dynasty of the Abbasides was, however, more favourable to Science. Almansor, the second, and Haroun al Rasched, the fifth Caliph of that race, were its able promoters.

In Bishop Pocock's translation of Abul Farraj, we find that Mamun Ben Rasched, (who lived A. D. 813,) "*amabat scientias et sapientes ac viros celebres: ejus tempore translati sunt multi libri ex Græcâ linguâ, in linguam Arabicam.*" p. 246. It is to this period that we think we may justly refer the passage of Chemistry (such as it then existed) from the Greeks to the Arabs.

The following may serve as a brief note of some Arab Alchemical writers mentioned by Borrichius and Du Fresnoy. A MS. in Arabic, in the Library at Leyden by Ostanes: M. Du Fresnoy considers this a translation from the Greek. The Commentary of Eidimir Ben Ali on Abul Hassam, and the Treatise of Geldek are both in the same depository. Geber who, afte Hermes, is in the greatest repute with the adepts, le many Treatises. Borrichius supposes him to have live prior to A. D. 830. His works were imperfectly printe until 1682, when a correct edition appeared at Dantzi, copied from a MS. in the Vatican. The next cited, in chronological order, is Rhazes or Mohammed Ben Zakaria of Korhassan, who died A. D. 932. He has the reputation of having first applied Chemical Science to the *Materia Medica*, and was an expert Physician. Farabi was a great traveller, and is reputed to have acquired a large and varied fund of Philosophical knowledge. He was murdered by robbers in the woods of Syria, A. D. 954. His works, which are numerous, are stated to be in MS. in the Library at Leyden. The time at which Michael Psellis lived is not certain, he was of Constantinople. Leo Allatius de Psellis, &c. Roma, 1634. There is a pretty little story made out of the history of Adfar, a sage Arabian adept. Morienus, a Roman, left his Country for the sake of participating in the Hermetic learning of Adfar and Kalid, who is reported to have been a Caliph or Sultan of Egypt; to these Morienus communicated the *arcanum magnum*, and then mysteriously withdrew himself from Royal favour, returning to his original solitude in Jerusalem. Morienus's Treatise was written in Arabic, but translated into Latin by Robertus Castrensis, A. D. 1182 Morienus is supposed to have lived at the middle of th XIth century; he was much younger than Adfa and probably rather older than Kalid. The translatic of a work referred to Kalid, may be seen in Mangetu

The last Arabian writer whom we need cite is E come out of its captivity in Babylon, and they will find their proper level as true Physicians for the soul and body, dispensing the leaves of the tree of life for the healing of the nations." It may be fair to state, that the author professes himself indebted to the writings of Jacob Behmen for these his first principles. All we need say is, that the pupil seems to have been well worthy of his instructor.

"Tribus Anticyris caput insanabile."

Poetry of the Alchemists.

The Alchemists did not disdain the flowers of Poesy, as an elegant mode of conveying their instructions. Of this writing we confine ourselves to the introduction of only two specimens.

But holy Alkimy of right is to be loved
Which treateth of a precious medicine,
Such as trewly maketh Gold and Silver fine
Whereof example for testimonie
Is in a City of Catilony
Which Raymond Lully, knight, men suppose
Made in seven images, the trewth to disclose;
Three were good silver, in shape like ladies bright,
Every each of four were gold and did a knight
In borders of their clothing like appeare,
Signifying in sentence as it sheweth here.

1. Of old horse-shoes (said one) I was yre,
Now I am good silver, as good as ye desire.

2. I was (said another) iron fet from the mine,
But now I am Gould pure, perfect, and fine.

3. Whilom was I copper of an old red pann,
Now I am good silver said the third woman.

4. The fourth said, I was copper grown in the filthy place,
Now am I perfect gold made by God's grace.

5. The fifth said, I was silver, perfect thorough fine,
Now am I perfect gold, excellent, better than the prime.

6. I was a pipe of lead well nigh two hundred yeare,
And now to all men good silver I appear.

7. The seventh said, I leade am, gould made for a maistrie,
But trewlie my fellowes are nerer thereto then I.

Norton's *Ordinal of Alchemy in* Ashmole's *Theat. Chem. Brit*. p. 20.

The following may serve as a specimen of the symbolical language adopted by the Adepts, for the purpose of concealing their processes from the uninitiated vulgar. For this purpose the metals were spoken of by their planetary designations; a method which first originated in Ages of the most remote antiquity. Thus Gold was the Sun, Apollon, and the sign ⊙ was found by Porson to stand for Apollo, in the margin of an ancient Greek MS. Silver was the Moon, and so of the rest. The passage further shows the early use of the word amalgamation.

But yet more kyndly som other men don
Fermentyng theyer Medcynes in thys wyse,
In Mercury dissolvyng both Son and Mone.
&c. &c. &c.
Som other ther be whych hath more hap
To touch the trothe in parte of Fermentinge,
They Amalgam ther bodys with Mercury like papp.

From Sir George Ripley's *Compound of Alchymie in* Ashmole's *Theat. Chemicum*, p. 174.

We must here conclude our notice of the Alchemists. It is not, however, to be by this understood that the pursuits of the Hermetic Philosophy fell suddenly into disrepute and disuse, but that as the writers with which we become acquainted at the beginning of the XVIIth century, had imbibed from Bacon a more just spirit and method of investigation, they gradually converted the crude mass of undigested facts, collected by the Alchemists, into the foundations of a regular Scientific inquiry into the constitution of nature, and the agency of these laws impressed upon matter. Of the last English Alchemists, we know of no other account than the following, given in the History prefixed to Mr. Brande's *Chemistry*, vol. i. p. 25.

"In later times we have had two or three believers in transmutation. In the year 1782, Dr. Price of Guildford, by means of a white and a red powder, professed to convert mercury into silver and gold, and is said to have convinced many disbelievers of the possibility of such change; his experiments were to have been repeated before an adequate tribunal, but he put a period to his existence by swallowing laurel-water."

"Another true believer in the mysteries of this Art, was Peter Woulfe, of whom it is to be regretted that no biographical memoir has been preserved. I have picked a few anecdotes respecting him from two or three friends who were his acquaintance. He occupied chambers in Barnard's Inn while residing in London, and usually spent the summer in Paris. His rooms, which were extensive, were so filled with furnaces and apparatus, that it was difficult to reach his fire-side. A friend told me that he once put down his hat, and never could find it again, such was the confusion of boxes, packages, and parcels that lay about the chamber. His breakfast hour was four in the morning: a few of his select friends were, occasionally, invited to this repast, to whom a secret signal was given by which they gained entrance, knocking a certain number of times at the inner door of his apartment. He had long vainly searched for the Elixir, and attributed his repeated failures to the want of due preparation by pious and charitable acts. I understand that some of his apparatus is still extant, upon which are supplications for success, and for the welfare of the Adepts. Whenever he wished to break with an acquaintance, or felt himself offended, he resented the supposed injury by sending a present to the offender, and never seeing him afterwards. These presents were sometimes of a curious description, and consisted usually of some expensive Chemical product or preparation. He had an heroic remedy for illness: when he felt himself seriously indisposed, he took a place in the Edinburgh mail, and, having reached that city, immediately came back in the returning coach to London. A cold taken on one of these expeditions, terminated in an inflammation of the lungs, of which he died in 1805. He is the author of several papers in the *Philosophical Transactions*."

We conceive that our time may easily be employed more advantageously to our readers, than by repeating here the histories and attestations that have been handed down to us in favour of successful transmutations. Such, however, may be seen in the works of Boyle and Boerhaave. There is also an amazing tale of the kind in Helvetius's *Golden Calf*. The following, however, has been pointed out to the writer of this Paper by a friend, and is given as, perhaps, the latest recorded instance of expert juggling of this kind; especially as it proves that there are yet followers of Alchemy in the East.

"A few days before my arrival at Bassora in August, 1814, (says Major Macdonnald Kinneir,) Mr. Colquhoun, the acting resident at that place, received a message from an Arabian Philosopher, requesting a private interview, in order to communicate a most important secret. Mr. C. consented; and next morning the mysterious stranger was introduced to him: embracing the knees of the resident, he said he was come to supplicate the protection of the English from the cruel and continued persecutions of his countrymen, who, having understood that he had the power of transmuting the basest metals into gold, daily put him to the torture to wring his secret from him. He added, that he had just made his escape from Grane, where he had long been starved and imprisoned by the Sheck, and that he would divulge every thing that he knew to Mr. Colquhoun, provided he was permitted to reside in the Factory. My friend agreed to receive him, and in return he faithfully promised to afford a convincing proof of his skill. He accordingly retired and soon afterwards returned with a small crucible and chafing-dish of coals, and when the former had become hot, he took four small papers containing a whitish powder from his pocket, and asked Mr. C. to fetch him a piece of lead: the latter went into his study, and taking four pistol bullets, weighed them unknown to the Alchemist: these, with the powder, he put into the crucible, and the whole was immediately in a state of fusion. After the lapse of about twenty minutes, the Arabian desired Mr. C. to take the crucible from the fire, and put it in the air to cool: the contents were then removed by Mr. C., and proved to be a piece of pure gold, of the same weight as the bullets. The gold was subsequently valued at 90 piastres in the Bazar. It is not easy to imagine how a deception could have been accomplished, since the crucible remained untouched by the Arab after it had been put upon the fire; while it is, at the same time, difficult to conceive what inducement a poor Arab could have had to make an English gentleman a present of 90 piastres. Mr. C. ordered him to return the next day, which he promised to do, but in the middle of the night he was carried off by the Sheck of Grane, who, with a body of armed men, broke into his house and put him on board a boat, which was out of sight long before day-break."—*Travels in Armenia, Koordistan, &c.* p. 406.

We have, hitherto, passed by the claims of the Chinese to an early knowledge of Alchemy. Martini in his *Historia Sinica*, and Le Conte in his *Mémoires sur la Chine*, state that the Chinese assert Alchemy to have been known among them 2500 years before the Christian æra, but that they have no manuscripts on the subject. In the *Mémoires de l'Acad. de St. Petersb.* for 1807 and 1808, vol. ii. there are some extracts from a MS. on Chemistry, brought from China by M. Bournon. The title, when translated, runs thus: *Confessions du paisible Dragon*, composed by Maò-hhóa in the reign of the Emperor Ssoŭ-dsoūnn of the dynasty of Tânn, which is equivalent to A. D. 756.

In the first chapter the author says, "*Tout ce que l'homme peut sentir et observer par les sens, et tout ce qu'il peut concevoir par son esprit et par son imagination, est composé de deux principes fondamentaux le Yânn et la Ȳne, qui désignent le parfait et l'imparfait. Le Yânn est le puissant ou l'accompli, et le Ȳne lui est diamétralement opposé.*"

Of the Atmosphere (Hhiá-chēnn-kí) he says; this Hhiá-chēnn-kí is the kí which rests on the surface of the earth, and elevates itself to the clouds. When the proportion of the Ȳne which makes part of its composition is too great, it is not so perfect as the kí beyond the clouds. We might perceive the Hhiá-chēnn-kí by the sense of touch, but the elementary fire with which it is mingled, renders it invisible to our eyes. There are many methods which purify it and deprive it of a part of its Ȳne. This is done by substances which are modifications of Yânn, such as metals, sulphur (lieôu-hhouânn,) and Táne, or charcoal. These ingredients, when we burn them, amalgamate themselves with the Yânn of the air, and give new combinations of the two fundamental principles.

On the whole, although we suppose it just possible that the pursuits of Alchemy may have extended themselves into China, yet there seems little evidence on the subject. We have almost felt it a waste of room to notice M. Bournon's MS., for it is in perfect accordance with the well known character of the Chinese for devising such frauds, and for great skill in executing them, to suppose the whole a forgery, the object of which has been to produce an evidence of Chemical knowledge having existed among them, prior to its appearance in Europe. Thus they would pretend that the constitution of the atmosphere, and the nature of its ingredients, was known in China during the VIIIth century; precisely as explained in Europe at the close of the XVIIIth.

History of Chemistry.

We have admitted that it is to the medical writers of the XVIth century, that we are indebted for changing the pursuits of Alchemy into those of true Chemistry. The knowledge which the Adepts had gained by their unwearied efforts, all directed to one or two points, was of course itself limited; but it was upon that, as a foundation, that Basil Valentine, Paracelsus, and Van Helmont commenced their superstructure. These writers, to all of whom we are in various ways indebted, were busily employed in making the processes which they received from the Alchemists, subservient to the preparation of active medicines chiefly drawn from the mineral kingdom: while, at the same time, they had the difficult task of combating the established usages of the more mild, but less efficacious, preparations of the Galenical school of Physic.

Valentine.
Paracelsus.
V. Helmont.

While thus Medicine adopted Chemistry as an immediate auxiliary, Philosophy claimed its aid as a method of interrogating nature. On this ground there is no name so deserving of attention, as that of *Francis Bacon Lord Verulam*. This extraordinary man, whose writings bear the deepest stamp of originality and genius, pointed out to all the world the just paths to be pursued in Scientific investigation: nay, more, he set the example, by himself walking in those paths not unprofitably; making Science his relaxation from the cares of State, as it afterwards became his solace in years of degradation and affliction.

F. Bacon.

In the subsequent part of this introduction, we may name two or three of the great changes which Chemical creeds have hitherto undergone; but the nature of this work will by no means admit of that fulness of Historical detail, which we could with pleasure undertake. We have said more of the Alchemists than we intend to say of the Chemists, because we feel that we have parted from them for ever: but it may be possible yet to acknowledge our obligations to the Chemists, though briefly, when each substance, which their sagacity brought to light or investigated, shall come individually in review before us.

Basil Valentine describes several processes for obtaining nitric or sulphuric acids, and in his *Currus Triumphalis Antimonii* he explains the composition and properties of numerous medicines formed from that metal.

Basil Valentine.

Paracelsus was a bold and successful Physician, his writings do not seem to have tended so much to the

Paracelsus.

advancement of Chemistry, as to the defence of the active Chemical Articles recently introduced into the *Materia Medica*, such as calomel and the antimonial preparations. He sank at an early age under the consequences of a life of irregularity, and is buried at Saltzburg.

Van Helmont.

Van Helmont, a Physician of Brussels, succeeded to the knowledge, and supported the credit of the medicines of the two last named authors. His writings convey to us a favourable impression of a mind honestly searching for Truth; but his energies are directed more towards Medicine than to pure Chemistry. He first used the term *Gas* to designate all aëriform substances, atmospheric air excepted.

Kunckell.

Kunckell wrote on Glass-making, and he also discovered the method of obtaining Phosphorus, having, however, had some shown to him by *Brandt*, a Chemist of Hamburg, its first discoverer, who concealed the process from Kunckell, though he revealed it to Kraft of Dresden.

Brandt.

Glauber.

Glauber of Amsterdam was an experimentalist of first rate excellence; he wrote much, but he also worked much, and introduced many valuable improvements into the manipulations and apparatus of Chemistry. He introduced the process for obtaining muriatic acid, and described the method of separating ammonia from bones; he formed also the salts of that alkali. His discovery of the product of vinegar by the distillation of wood in close vessels, has not, until very recently, obtained the attention it deserved, though now it forms an important branch of our Manufactures.

The formation and incorporation of the Royal Society in 1662, by Charles II., together with a similar institution, the French Royal Academy of Sciences, formed in 1666 by Louis XIV., were great National measures, which, though at first they may be said to have owed their origin to the calls and claims of Science, in the end acquitted themselves of the obligation by ennobling its purposes, concentrating its energies, and enrolling among its votaries the most learned and dignified characters of the Age.

The Royal Society originated at Oxford, but its members removed their sittings from that place to London for the sake of greater assistance and more extensive utility. Among its earliest members was the Honourable *Robert Boyle*, a most amiable man, a diligent Philosopher, and a sound Christian. He wrote and published much, and with good effect, though originality of genius does not seem to have been his characteristic.

Boyle.

Hooke.

Dr. Hooke was the contemporary of Boyle, of a disposition far less amiable, but of genius more acute. Boyle and Hooke satisfactorily demonstrated the necessity of atmospheric air to the process of combustion; and the views which Hooke entertained were subsequently supported with great ability by *Mayow*. The opinions of Boyle, Hooke, and Mayow, upon the subject of combustion, though, as we now believe, the more accurate of the two, seem to have given way to the foreign doctrines advanced by Beccher and Stahl.

Mayow.

Stahl.

Ernst Stahl, a Chemist of great and deserved reputation, was the chief author of what is termed the Phlogistic Theory of Combustion. In this theory Phlogiston is considered an element of extreme subtilty, capable of existing as a constituent part of some bodies, and causing the appearance of fire whenever its particles are so liberated as to assume a violent vibratory motion that is natural to them. Every substance that it was possible to burn was supposed to contain Phlogiston, and every substance when it had been burned was thought to have parted with its Phlogiston. This continued to be the general belief for more than half a century, though the reasoning of Boyle, Hooke, and Mayow, together with the experiments of *Rey*, showing that metals did not lose but gained in weight by combustion, were decidedly opposed to such an hypothesis.

Hooke recognised the combination of oxygen in nitre, though that term was not applied to it till long afterwards. Mayow called it the *Nitro-aërial* substance, and demonstrated its necessity to animal respiration. He also obtained hydrogen by the action of iron upon diluted sulphuric acid. His examination of the mutual actions of saline bodies is, perhaps, the first germ of the doctrines of analysis depending on composition and decomposition. The sulphurets, both metallic and alkaline, are ably treated of in his works, and much of that system which is so forcibly sketched in the small portion of Newton's writings that is devoted to Chemistry, may be traced to the experiments, if not to the views, of Mayow. The whole of the doctrine of Chemical Attraction underwent great changes and improvements subsequently in the hands of *Geoffroy*, *Bergman*, *Berthollet*, *Pfaff*, *Proust*, *Wenzel*, *Richter*, *Higgins*, *Dalton*, *Wollaston*, *Gay Lussac*, and *Prout*.

Although, in the divisions of Science to which we adhere, Heat does not form a part of Chemistry, yet as the Chemists of the period we are examining invariably united these branches, we must now mention the discovery of the thermometer, an event which produced a decided and beneficial influence upon the progress of Chemistry in general. In regard to priority of claim to this valuable invention, authors are divided between *Drebbel*, of Amsterdam, and *Santorio*, of Padua: both lived in the latter half of the XVIth century. The Florentine Academicians, however, were the first to reduce the instrument to purposes of practical utility. But all their instruments wanted the essential of comparability. It seems doubtful; but *Dr. Halley* is said to have introduced as one fixed point of comparison, the boiling point of water, and *Newton* certainly made use of both this and the freezing point of water: thus obtaining two fixed points universally attainable, and rendering all thermometric indications comparable with each other. *Van Swinden*, *Fahrenheit*, *Martini*, *De Luc*, *Saussure*, *Six*, and *Leslie*, have published further illustrations, or have suggested improvements in this instrument.

To *Dr. Hales*, the author of the *Statistical Essays*, we must award the praise of having been the chief author of Pneumatic Chemistry, though it in some degree commenced with Mayow and Hooke. He refused high preferment in order that he might continue his Philosophical pursuits, which served for his amusement amidst the zealous discharge of parochial duty, a course which only closed with his life in 1761, at 84 years of age. His experiments on the gases were very numerous and of a miscellaneous character; but those in which he applied the same industry to investigate the respiration and chemical agency of plants are better directed, and still form an important portion of our knowledge in this branch of vegetable organization. *Herman Boerhaave*, of Leyden, was about nporary with Hales. He was a distinguished :ian, a good Chemist, and an excellent man. His Johnson is well known, and justly admired.

Black was Professor of Chemistry at Edin- . In Chemistry, his great discovery was that of iic acid gas, which he obtained from decomposing lkaline and earthy carbonates. But even this, as it was, was exceeded, in originality and beauty, e grand addition which he made to Physics of nowledge of *Latent Heat*, about the year 1760. HEAT, Art. 249.) The practical importance of loctrine was readily seen and employed by the iechanical genius of Watts.

lowing a sort of chronological order, the name of *ian* next occurs. He was of Upsala, in Sweden, nay be considered, in some sense, the earliest ır analyst whose name occurs in the History of istry. His labours tended to the acquirement of re intimate acquaintance with the properties of ınces for the purpose of their separation, and also ɔse metallurgic processes so important to his ry in particular. He died at the early age of 49, tyr to his assiduity in the cause of Science.

e Honourable *Henry Cavendish*, *Dr. Priestley*, ive of Yorkshire, and *Carl Wilhelm Scheele*, a e, are names which may now be referred to, pally in connection with Pneumatic Chemistry. ley commenced by repeating the experiments of e, Mayow, and Hales, on gaseous bodies, and he greatly improved upon the apparatus formerly yed for these researches, leaving it much the same ployed at the present day. He is considered as g discovered oxygen gas on the 1st of August, ; which he obtained by concentrating the Sun's ıpon red precipitate over mercury. He named his gas *dephlogisticated air*, though, in fact, it was the which had been obtained from nitre by Hooke Iayow. He diligently traced the functions of this the processes of animal and vegetable respira- Mr. Cavendish discovered muriatic acid gas, 'riestley further investigated its properties. The also separated ammoniacal gas from the muriate : action of lime: and discovered that which is now sulphurous acid gas: examining also the pro- s of nitrous gas, which had been imperfectly n to Mayow.

e more prominent facts which were brought to by the high talents of Mr. Cavendish, most assi- ly, yet cautiously exerted, were the complete ledge of hydrogen gas, which, though the sub- e had been obtained before, was quite disregarded his time. These researches led him to the bril- discovery of the composition of water, which he ɔefore the Royal Society in 1784. (Vide ELEC- rY, Art. 167.) Thus was the synthesis of water ıplished.

e merits of Scheele were discovered and brought ht by Bergman, who wrote the Introduction to the vork of the former, *Chemical Experiments and cations on Air and Fire.* It seems that Scheele vered, independently of Priestley, many of the tant phenomena made known by the latter about ıme time. His observations on the radiation of are highly interesting; but the discovery of chlo- or Dephlogisticated Marine Acid, as he called it) be considered his noblest achievement. This ɔlace during his excellent examination of manganese. He also commenced the genuine Chemical examination of the vegetable acids. Lastly, the *Essay on Prussian Blue* must be mentioned with high commendation. He died at the early age of 44.

Lavoisier

We have now arrived at the æra of *Lavoisier*, which produced another great revolution in the Chemical theory of combustion. The admirable Philosopher, whose name we have just cited, may be considered as the chief opponent to the doctrine of phlogiston as introduced by Stahl. That there existed no such body as phlogiston was asserted by Lavoisier, chiefly on the ground that substances which had undergone combustion weighed more than they had originally done; which they ought not to do if they had parted with some element previously combined. This operation was traced to the union of oxygen with the combustible body. The last and the ablest of the supporters of phlogiston was *Mr. Kirwan*, a distinguished native of Ireland. He published a small work in defence of his views. This work was answered by *Lavoisier*, and his associates *Berthollet*, *Monge*, *Fourcroy*, and *De Morveau*, who, having taken Kirwan's work, republished it with their arguments and experiments, attacking each chapter separately. Never was there a contest more purely conducted towards the investigation of Truth; and never one in which the erroneous combatant gained for himself, by his candour, the admiration of impartial judges more completely than Mr. Kirwan. From that day phlogiston has disappeared from all Chemical writings. It seems to us most extraordinary that a belief in it ever should have prevailed to the extent that it did: for there were abundance of facts and experiments which ought to have overturned it long before. These facts, however, Lavoisier has the merit of having systematized and brought to bear upon the question. But here we stop, and do not concede to him the merit of absolute originality in those experiments by which the antiphlogistic doctrines were supported. On this subject we fully agree with Mr. Brande, in the following observations taken from the Historical Introduction prefixed to his *Chemistry*, published in 1821.

Kirwan

"It requires no deep inquiry, or minute investigation, to detect in the researches of Priestley, Scheele, and Cavendish, the materials of which their contemporary, Lavoisier, aided by several celebrated Chemists of the French School, constructed his new theory; and a retrospect of the works of Mayow and Hooke will show that the antiphlogistic system almost necessarily arose out of a combination of their views with the more modern discoveries."—p. 172.

"If we look to the abstract facts on which it (the antiphlogistic theory) rests, we shall search in vain, either in the works of Lavoisier, or in those of his contemporaries; they were exclusively furnished from other quarters; and, without any undue prejudice, of which indeed Science should always stand divested, they will I think chiefly be found in the writings of Mayow and Hooke, and in those of Priestley and Scheele. The prominent features of the French theory are its explanation of the theory of combustion and acidification, the presence of oxygen being deemed essential in both cases. That air is the food of fire was known in the remotest Ages; that it causes the increase of weight sustained by metals during their fusion and calcination, was shown by Rey early in the XVIIth century; that a part only of the atmosphere is concerned in the support of flame, was explained by Hooke in 1667; and that the vital or igneous spirit (as he terms it) of the atmosphere, is concerned in the formation of acids, was asserted by Mayow in 1674. Here, without advancing into the XVIIIth century, we have in explicit detail, all the facts and arguments requisite for the construction of the French theory; but if to these we add the discovery of oxygen by Priestley, and of the composition of water by Cavendish, what then becomes of its claims to originality?"—p. 182.

The name and talents of Lavoisier did much for the introduction of the new system of Chemical nomenclature. From considering it the principle of acidification, he gave its present name to oxygen gas; azote, hydrogen, and carbonic acid gas, are also terms of the same æra.

Lavoisier's principal discovery, was the actual combustibility of the diamond, which had before been suspected by Newton; showing also its Chemical identity with common charcoal.

For the last and greatest advancement in Chemistry, we are indebted to the aid of Electricity. Dr. Priestley is, perhaps, the first who thus called in the powers of a sister Science. At least he seems first to have noticed and examined an experiment of Warltires, tending towards the synthesis of water by firing a mixture of oxygen and hydrogen gases. Mr. Cavendish pursued these researches, and was thus the first to demonstrate the composition of water. This was in the year 1781; and in 1789, the associated Dutch Chemists, Paets, Van Troostwyck, and Dieman, effected its decomposition by a varied application of the same agent. It is not, however, to ordinary Electricity that Chemistry is indebted for its greatest advancement, but to that species of action which arises from the Voltaic pile.

Volta

In repeating Galvani's experiment upon what he called the Animal Electricity, made by placing some zinc in contact with the nerve, and some copper in contact with the muscle of a recently killed frog, and then forming a contact between the two metals, by which a muscular convulsion was produced, Volta was led, about the year 1791, to the discovery of that beautiful series of mutual electric actions between the metals and other substances, which has subsequently borne his name. Mr. Cruickshanks improved the construction of the pile by converting it into a trough; and in 1800, Messrs. Nicholson and Carlisle may be said to have first witnessed the Chemical action of the pile in a most important instance, namely, the decomposition of water. In 1803, Hisinger and Berzelius greatly extended the knowledge of Electro-chemical agencies, by publishing a beautiful series of experiments, developing the law that "oxygen and acids are accumulated round the positive pole of the battery, while hydrogen, alkalis, earths, and metals are accumulated round the negative pole."

Davy.

The *Philosophical Transactions* for 1807 contains Sir *Humphrey Davy's* Paper, in which the Chemical agencies of Electricity are still further developed; and the brilliant experiment of the decomposition of the alkalis, with considerable evidence of the real nature of the alkaline earths, is described in one of the most interesting Memoirs ever presented to Science.

From this period the History of Chemistry does not present any very marked features to arrest our attention. It has continued steadily to advance, but without making any of those gigantic strides which we have felt it necessary thus briefly to mention. Analysis of all kinds has been in a state of successive improvement. In France, this most important branch of the Science has been most successfully directed to the examination of the vegetable contents of the *Materia Medica*, with a view to practical purposes: while, at the same time, *Dr. Prout* in England, and *Professor Berzelius* in Sweden, have laid the foundations of noble researches in the Chemical physiology of animal bodies: from which ultimately the healing Art will unquestionably derive signal advantages.

In concluding this most circumscribed outline of the History of Chemistry, we may perhaps be allowed to express a faint shade of regret, which nevertheless has frequently passed over our minds within the space of the last five or six years. Admiring, as we most sincerely acknowledge that we do, the Electro-magnetic discoveries of Professor Oersted and his followers, we still as Chemists fear that our Science has suffered some degree of neglect in consequence of them. At least, we remark that during this period good Chemical analyses and researches have, with a few exceptions, been rare in England; and yet it must be confessed there is an ample field for Chemical discovery. How scanty is our knowledge of the suspected Fluorine! Are we sure that we understand the nature of Nitrogen? And yet these are among our elements. Much has been done by *Wollaston*, *Berzelius*, *Gay Lussac*, *Thenard*, *Thomson*, *Prout*, and others, with regard to the doctrine of *Definite Proportions*, but there yet remains the ATOMIC THEORY. Is it a representation of the laws of nature, or is it not? This is a point of vital importance to Chemistry: it yet remains undetermined. Let the Chemist and the Mathematician (for both are required) unite their powers for the solution of this problem.

For the History of Chemistry the reader may consult Borrichius, *de ortu et progressu Chemiæ*, 4to. (reprinted in Mangetus;) Bergman, *de primordiis Chemiæ*, Opuscula, vol. ii. or Upsal, 1779. Du Fresnoy, *Histoire de la Philosophie Hermétique*, 3 tom. 18mo. Paris, 1742; Boerhaave, *Elementa Chemiæ*, Lugd. Bat. 1732; Gmelin, *Geschichte der Chemie*, Göttingen, 1797, 3 vols. 8vo.; Fourcroy, *Discours Préliminaire* to his System, in 6 vols. 4to.; Brande, *Historical Introduction* to his Chemistry, in 3 vols. 8vo. Lond. 1821.

For the Alchemists, P. Borellus; also a catalogue of English Alchemical Authors in the translation of Helvetius's *Golden Calf*; Mangeti *Bibliotheca Chemica*, 2 tom. fol. Geneva, 1702, contains a copious assemblage of Alchemical writings; *Theatrum Chemicum* (per Laz. Zetznerum) Argentor, 6 tom. 8vo. 1659; Elias Ashmole, *Theatrum Chemicum Britannicum*, fol. 1652; *Lives of the Alchemists*, (Barret,) London, 8vo. 1815.

We subjoin a chronological list, which will be found convenient, as giving the date of the birth and death of the Chemists mentioned in this introduction. It does not contain the Alchemists, as these have been already noticed.

	Born.		*Died.*
Basil Valentine	publ.	1604	
Paracelsus	1493	....	1541
Cardan	1501	....	1576
Van Helmont	1557	....	1644
Libavius	1588	....	1616
Francis Bacon	1560	....	1626

	Born.		Died.
rio	1561	....	1636
s	publ.	1602	
	publ.	1630	
	1571	....	1630
r	publ.	1651	
ke	1602	....	1686
le	1617	....	1692
r	1625	....	1685
	1564	....	1644
lli	1608	....	1647
	1627	....	1691
ell	1630	....	1703
	1635	....	1702
y	1645	....	1715
y, jun.	1677	....	1743
n	1642	....	1727
e.	1645	....	1697
rg.	1652	....	1715
	1656	....	1741
	1458	....	1521
	1660	....	1734
n.	660	....	1742
ave	668	....	1738
	1677	....	1761
heit.	1686	....	1736
y.	1672	....	1731
af.	1709	....	1782
ck	1718	....	1797
rigg	1711	....	1800
er	1718	....	1784
	1723	....	1762
ide	1726	....	1778
	publ.	1769	
	1728	....	1799
a.	1729	....	1805
lish	1731	....	1810
ey	1733	....	1804
an	1735	....	1784
	1735	....	1819
ford	1695	....	1779
	publ.	1789	
	publ.	1782	
	1737	....	1815
rd		....	1795
	publ.	1805	
e	1742	....	1786
ier	1743	....	1794
oy	1755	....	1809
	publ.	1792	
le.	publ.	1782	
	publ.	1792	

CHEMICAL APPARATUS.

re any attempt is made to explain the principles Science, it may be advisable to describe the Innts employed in Chemical researches.

Laboratory is the building or room wherein the st carries on his operations. In describing such ing with its requisite furniture, it is intended to n, as far as our limits will allow, all that is ne- for an ample range of Chemical research: but extent of the apparatus should appear a formi- bstacle to the commencement of this fascinating portant study, it must be premised that we are about to describe more than it may be in the power of every person to command. It will be easy, however, for any one to select whatever instruments are essential to that particular branch of the Science which he may design to investigate. From the very great improvements which the last twenty years have produced, the cumbrous vessels and tedious processes of the early Chemists have given place to simpler and more delicate modes of experimenting. Formerly, the Instruments of the experimentalist and the manufacturer were identical; to the latter they remain the same, as quantity is his object, but in the present improved state of Chemistry, the blast-furnace and the evaporating pan have in most instances given way to the blowpipe and the watch-glass. It is true, that in a well-appointed Laboratory they are still essential, but the command of a spare room and a small stock of instruments will enable any person to verify processes, and even to prosecute new objects of research with little cost or inconvenience.

Historical Introduction.

It scarcely need be remarked, that in a Science depending so much on manipulation, and the habit of accurate observation, a little practice will teach more than volumes of reading. Numerous minutiæ, too unimportant and tedious for description, may easily be gained by experience, or by the aid of a skilful instructor. A Work, however, expressly devoted to this branch of the subject, has been recently published by Mr. Faraday, of the Royal Institution; it will be found ample in its details, and invaluable to any one entering upon Chemical studies.

Perhaps, on the whole, the most advantageous form for a Laboratory, would be that which allowed of one ground-floor room, a cellar beneath, and a chamber above. The cellar serves as a convenient store-room for glass and earthen vessels not constantly in use, carboys of acids, and other things that require to be kept in large quantities; but the main object of this arrangement, is to keep the ground-floor room free from dampness, which is extremely injurious to the furnaces and to all iron work, detaches the labels from bottles, and dissolves the deliquescent salts in the moisture they imbibe. On the ground floor, a space of at least six feet in width along one side should be appropriated to the range of furnaces, and under this part the cellar ought not to extend, as no floor could support the weight without arches, and no wood ought to enter into its structure. The floor of this part should be brick or stone, but the remaining part of the room may have a boarded floor. Over the whole of this fire-proof space, a chimney should extend, and may taper upwards, so as to become of the ordinary size at the top of the building. If the front of this chimney be supported by pillars or arches, the height should everywhere be sufficient for a person to walk freely under without stooping. The main object of this capacious chimney, is for the purpose of allowing all acid fumes and noxious gases to escape without being diffused throughout the air of the room.

Under this open chimney, the flues from all furnaces may be made to terminate. In the arrangement of these furnaces, convenience must principally be studied; and for their construction individually, we refer to the descriptions hereafter inserted. It is desirable so to arrange, that as some one fire must always be kept in the Laboratory, that one should heat a sand bath, in which evaporations may be going on simultaneously with other operations. Of all the furnaces so contrived, the one now in use in the Laboratory of the Royal Institution, standing quite free from any wall, seems the most simple and useful. Its construction may be seen in p. 90 of Mr. Faraday's Work.

We now proceed to describe the furniture of the Laboratory in alphabetical order, for the convenience of reference.

Air-pump. For a description of this instrument, see Pneumatics.

Alembic. See *Distillatory Apparatus.*

Balance. For the particular description of this most important instrument, with a review of those mechanical and statical considerations which influence its construction, we refer to the word Balance, in the *Miscellaneous Division* of our Work. A well-furnished Laboratory ought to contain three Balances, at least; the largest, capable of weighing several pounds; a middle size, for weights from a thousand grains to about one pound; and, lastly, a very delicate beam for the purposes of accurate analysis. Some Balances have been constructed so as to possess great sensibility, even when bearing a considerable weight in each scale, but such are very expensive. The Royal Society is in possession of a remarkably fine instrument of this description, made by Ramsden. (*Jour. de Phys.* xxxiii. p. 144.) The scales in common use will turn with $\frac{1}{100}$ of a grain, and may be loaded with 1000 grains in each pan, without materially diminishing the sensibility. The beam ought to be made of some metal which will resist the acid fumes of the laboratory; and for this purpose platinum has been sometimes employed, but it is expensive, and rather liable to permanent derangement of form. Bell-metal has recently been suggested, as, although it is flexible, the form is restored by its elasticity. The pans, and even the lines by which they are suspended from the beam, should be of platinum. The instrument ought always to rest under the protection of a glass case. The weights also should be of platinum, as not being liable to oxidation or corrosion, and admitting a ready purification from grease and dirt by exposing them to a red heat.

Balloon. A large glass globe used as a receiver, having a short neck adapted to the reception of the beak of a retort. See Plates, Chemistry, fig. 1.

Barometer. A general description of this instrument will be found in Pneumatics and Barometer.

In the Laboratory it is essential to ascertain the atmospheric pressure during any quantitative experiment on a gas; as, without such observation, we cannot know the real mass of any compressible fluid confined in a vessel of given capacity. There is, however, another important consideration attendant upon this problem; for, supposing both the volume of the gas, and the atmospheric pressure, the same in two cases, yet if the temperatures differ, it is obvious that owing to the very great change which heat produces in the elastic force of gaseous bodies, the quantities in the two cases will not be the same.

All experiments, therefore, are referred to a standard pressure and temperature; and as they are necessarily made under great variety of circumstances, it becomes necessary to reduce the results, when so obtained, to what they would have been, had the standard pressure and temperature existed. The rules for this calculation will be given in a subsequent part of this Paper, in describing the Physical Properties of Gases.

Bladders are frequently employed for the transfer of gases. Those of the calf and ox are preferred; stop-cocks are fastened to the neck so as to make them air-tight, and they are then fit for use. It has been attempted to cover them with a coat of oil-paint; this, however, soon cracks and peels off. Perhaps a delicate varnish holding caoutchouc in solution might be advantageously adopted. Bags of fine silk thus varnished have been sometimes substituted for bladders.

Blowpipe. For an ample description of this instrument, which belongs not to Chemistry only, see the word in the *Miscellaneous Division* of this Work.

Capsule. A small evaporating dish.

Crucibles are vessels for containing substances that are to be exposed to very violent degrees of heat. They are made of various forms, figs. 3, 4, 5, 6, and 7. Some have lids, and some have not. The materials of which they are made are various, according to the purposes for which they are designed. Platinum renders on this occasion essential assistance to the Chemist from its infusibility in all furnaces, but it does not well withstand the continued action of alkalis, and, still less, that of one genus of salts, the nitrates; and, if exposed without protection in a common coal fire, the vessel is frequently rendered brittle, and spoiled by the arsenic and sulphur which is found in some varieties of coal. Pure silver Crucibles are extensively used in the analysis of minerals, as they resist the action of alkalis; and though they are unable to bear more than a low red heat, yet that is amply sufficient for the analyst's purpose. Indeed it would appear, that even if the Crucible would bear it, little is to be gained by a greater elevation of temperature. In all cases, if possible, it is better that the platinum, or silver Crucible, be imbedded in sand within a common earthen one: thus the heat is more gradually applied, and the crucible is protected from the immediate action of the fire. Crucibles are also made of iron, but such are seldom used by the experimental Chemist. A very delicate and cleanly sort of Crucible is made of porcelain or Wedgewood ware, but these are extremely liable to crack, if either heated or cooled without great caution.

In using platinum Crucibles care should be taken to avoid those substances from which Chlorine may be disengaged. Also not to fuse nitre, nor either of the caustic fixed alkalis in them, for, in this case, a protoxide of platinum is formed and dissolved in the salt. Not to calcine in them such bodies as may leave a metallic residuum, such as the metallic salts from vegetable acids, nor mixtures which may produce phosphorus. When such metallic oxides are calcined as have but feeble affinity for oxygen, (as lead, bismuth, copper, cobalt, nickel, antimony, &c.) the temperature must never be raised above a moderate redness; for although these oxides are not decomposable *per se*, their reduction may take place at a high temperature, in consequence of the affinity of their metals for platinum. In long continued calcinations, the Crucibles must be protected as much as possible from the immediate contact of the fuel; for the metal is very apt to receive injury from substances accidentally met with, though in small quantities in the coke or coal, as we have already remarked; and even when these are the purest, silicon is present, which in the course of time unites with and injures the Crucible, by rendering it brittle.

For enduring a violent furnace heat, the common Hessian Crucibles, made of clay and sand, are to be

Historical Introduction.

preferred; the Cornish Crucibles also are excellent; they are, of course, slightly acted upon by alkaline fluxes and vitrified oxides, but are, on the whole, the best for metallic reductions. In some cases, to prevent the adhesion of the metal to the bottom of the Crucible, it is advisable to smoke the inside well over a lamp, or even to line the interior of the Crucible with pounded charcoal, made into a paste with a small quantity of linseed meal and water. The black-lead Crucibles are made of that mineral and fine clay; they bear the most violent heats, and are little disposed to crack, but they are quite unfit for retaining fluxes. Their principal use is for the fusion of metals; and the larger kinds are easily converted into most convenient portable furnaces.

Distillatory Apparatus. The process of distillation depends upon this principle, that by the application of heat many liquids, and even solids, may be raised in the state of vapour, and again condensed when that vapour arrives in such a situation as to lose the heat which had been communicated to it. Thus a separation of pure from impure is effected. For instance, in the Laboratory it is essential to have a copious supply of pure water. Now the common spring water is usually contaminated with earthy and alkaline salts, and with some mineral acids. To remove these, distillation is resorted to. Fig. 8 represents a common Laboratory still. This instrument frequently forms a part of the range of furnaces underneath the open chimney, but it may with equal or greater convenience be placed over a portable furnace, as in the Plate, and in this form its construction will be more obvious. A is the body of the furnace, B its door. C the top, or lid of the furnace, is removed; and in its place is the body of the still fitting in like a pan to come over the fire. H is the head of the still fitting well to the body, and continued by a long neck D, which enters the worm tube at F. E is the refrigeratory, a wooden vessel, filled with cold water, through which the worm tube passes and issues at G. Suppose the body of the still filled with pump water, and placed over the furnace; as soon as ebullition commences, the steam will proceed towards G, its only outlet: but in its passage thither, being condensed by the cold water surrounding the worm, it will issue in a small stream from the orifice G.

By the early writers the term *alembic* was given to instruments for distillation, and is still employed by some. Fig. 9 is a representation of a very convenient form, in which the necessity for a worm tube is avoided; and it may be used either for distillation over the fire immediately, or with the intervention of a water-bath. It consists of four pieces; A is the boiler which fits into the top of a portable furnace, as far as the projecting shoulder A. At E is an opening closed by a cork, through which additional supplies of the liquor to be distilled may be introduced without disturbing the apparatus. B is the water-bath, which sinks almost to the bottom of the vessel A, and is thus deeply immersed in the hot water. This part is only occasionally fitted in to distil such spirituous liquors as do not require the greater heat of the fire, and, in fact, would be injured by unprotected exposure to its action. C is the capital, or part in which the vapour is condensed; the form is conical, and a small channel runs round the bottom internally to collect the condensed fluid as it trickles down from the under surface of the cone. From this channel it is conveyed into any convenient vessel by a pipe terminating at F. The upper surface of the cone forms the bottom of the vessel D, which is kept constantly full of cold water for the condensation of the vapour, and hence is called the refrigeratory. This water is let off by the stopcock *e*, when it becomes warm, and a fresh supply is poured in at the top, which is left uncovered for the purpose. The whole may be made of tinned copper; and this alembic possesses a great advantage over the still before described, that all its parts may readily be cleaned; while, if the still with the spiral worm be employed for strongly scented waters, or volatile oils, it is extremely difficult to get it free from their contamination. Some trouble is caused by the necessity of frequently changing the water in the refrigeratory; and it is essential that the cone be made to taper upwards to a considerable height, as otherwise the drops are apt to fall back into the boiler, or body of the still. This form of the instrument is, probably, more ancient than the spiral condensing worm, as it is only an improvement upon the simple alembic of the Alchemists.

Fig. 10 represents this last-mentioned instrument. It consists of two parts, the cucurbit A, into which the substance for distillation is put; and B, the capital, or part wherein the vapour is condensed; the neck C of the cucurbit fits into the capital and round the rim of the latter at D D: there is a channel in which the liquor from the top of the capital is collected and carried by a pipe E into the vessel destined for its reception. Sometimes the whole is of one piece, and in this case there is a stopper at F for the admission of the liquor to be acted upon. Silver or glass are the materials of which this instrument is usually formed, and it may be conveniently used over a lamp, or in a sand-bath. The bottom of the cucurbit, if made thin, will bear a considerable heat.

The most simple, and, for Chemical purposes, the most common, apparatus for distillation, is the *retort* and *receiver*.

The *retort* is either plain (fig. 11) or tubulated, (fig. 13,) and fitted with a ground stopper at the top. A is the body for the reception of the substance, B is the neck, and C the beak which is fitted into the neck of the receiver. (fig. 12.) In some cases, also, luting is applied to keep the vapours enclosed within the vessels. Retorts are made of different substances; as lead, porcelain, earthenware, and glass; the latter may conveniently be used over an Argand's lamp; and will, if good, bear any heat below that at which glass fuses.

When the plain retort is used, a long funnel, (fig. 15,) called a *retort funnel*, is extremely convenient for pouring in a liquid without wetting the neck of the retort.

The *receiver* (fig. 12) is the vessel into which the distilled liquid drops from the beak of the retort; and in some cases to effect the entire condensation of the vapour, it is necessary to keep the receiver immersed in cold water, or even in a freezing mixture.

The *adopter* (fig. 14) is employed to prolong the distance between the retort and receiver. The beak of the retort is inserted at one end, and the beak, or small end of the adopter, in a similar manner, enters the mouth of the receiver. These vessels are usually made of glass.

Fig. 16 represents a very convenient little retort easily made from a piece of glass tube, and which may, if necessary, be called the *tube retort*.

Dropping Bottle. A common bottle of any sort with a tube passing through the cork, having a capillary orifice. This is a most useful little instrument; as it is obvious, that if the bottle be half full of distilled water, and held in the hand when inverted, the expansion of the air from the warmth of the hand will propel the liquid, drop by drop, from the orifice of the tube. See fig. 17.

Dropping Tube. This is represented in fig. 18. It is useful to add gradually any liquid reagent to a solution; for the lower orifice being extremely small, the tube may be filled by sucking the air out from the larger end, and the finger applied to the orifice from which the mouth is removed, prevents the escape of the liquid from the tube, until it is brought to the vessel for which it is designed; and when there, regulates to a drop the quantity suffered to descend from the tube.

Drying Instrument for Precipitates in Filtres. A (fig. 19) is an Argand lamp, B is a vessel containing water to be boiled by the lamp, with a sort of chimney by the side for the escape of steam. C is a glass vessel, which, resting on a rim, sinks into the water; and within this conical glass the filtre to be dried is placed.

Eudiometer. Of this instrument there are several kinds; the earliest was employed by Priestley, in consequence of his discovery that nitrous gas absorbed oxygen from atmospheric air, and produced a substance absorbable by water. This method will be described hereafter, but for the experiment itself a graduated glass tube is sufficient, with another smaller one of known capacity, by which to measure the quantities of the respective airs submitted to experiment. Fig. 20 represents Priestley's instrument.

Volta's Eudiometer consists of a very strong glass tube, about seven inches long, open at the lower end only, and graduated into hundredths of a cubic inch. (fig. 21.) Very near to the top of the tube a short piece of wire passes through, and is cemented into each side of the tube, leaving a distance of about $\frac{1}{20}$th of an inch in the middle of the cavity of the tube between their two ends. When a mixture of gases, that may be united by the electric spark, is confined in this tube, one of the wires is connected by a chain with the outer coating of a charged jar; then if the glass knob be brought into contact with the other wire, a discharge takes place, causing a strong spark to pass between the ends of the wires within the tube, and thus the union of the gases is effected. The French close the lower end of this Eudiometer with a stopcock, and give a more complicated form to the whole instrument; but it is thereby rendered more liable to be burst by the violence of the explosion. In England the Eudiometer generally stands over the mercurial trough at the time of an experiment, and is supported by an iron clamp, which by means of a spring allows of some elevation at the moment of the explosion, but not so much as to raise the tube above the surface of the mercury. It is an advantage to be able to sink the Eudiometer down into the fluid, so that the exterior portion may be on a level with that on the interior of the tube, otherwise a calculation is necessary.

To these instruments we must recur hereafter when a greater knowledge of Chemical agents may make their use more intelligible. Fig. 22 is Dr. Hope's Eudiometer; fig. 23 is Mr. Pepy's; figs. 24 and 25 Davy's; and fig. 26 is a graduated glass tube as employed by Berthollet.

Evaporating Dishes, or *Capsules,* are generally made of Wedgewood's ware, either in the form of shallow pans, (fig. 27,) or segments of a sphere, (fig. 28;) for some purposes dishes of copper, platinum, or silver, may be employed; and for minute experiments a watch-glass is a most convenient vessel.

Files. Of these different sorts are required, but especially the three-cornered file for cutting a small notch in glass tubes, after which they easily break in the place required. Also the kind called Rat's-tail, as with these perforations are readily made in corks, through which glass tubes have to be passed.

Filtre. The process of filtration is so generally known as to render all description unnecessary. For some purposes a vessel made of porous stone is employed, or even a jar with a stratum of sand at the bottom. Hair sieves, flannel bags, and muslin, or a piece of tow in a common tunnel. For all delicate purposes in the Laboratory a piece of unsized paper is preferable. If the filtre is large it must be folded into a conical form, and placed within a glass tunnel, but in all cases it is advisable to avoid the use of filtres as much as possible. The object of filtration is generally to obtain a precipitate, that it may be dried and its quantity ascertained; now it is scarcely possible to remove the whole of the filtered substance from the paper without loss; and if the precipitate be dried upon the filtre, unless the paper be reduced to exactly the same state of dryness as at first, a fallacious weight is introduced. In most cases a precipitate will in a reasonable time sink down to the bottom of a fluid with which it is mixed, and the clear supernatant liquid may be drawn off by a sucking tube, (fig. 18;) but as a paper filtrer is sometimes necessarily employed, the following artifices are not without their utility.

From the same sheet of paper make a double filtre, that is, one filtre fitting within another. Use both together, and dry both together. Then take the one containing the precipitate out of the other, and by placing the empty one in the scale which contains the weights, a counterpoise is obtained, and all further calculation rendered unnecessary,

Sometimes the precipitate is to be dried at a red heat; and although the ashes remaining after the combustion of a small filtre do not amount to more than $\frac{1}{10}$th of a grain, and might easily be allowed for, yet frequently the precipitate is of such a nature that the carbonaceous matter would at a high temperature produce decomposition. Perhaps in such a case the following method is as short as is consistent with accuracy.

Use the double filtre as before. Reduce the whole to such a state of dryness as may leave the precipitate state coherent, but not pasty. By separating the filtres, and using one as a counterpoise to the other, the weight of the precipitate in this state is known. Let this weight $= a$. Detach some of the precipitate from the filtre, and put it into a platinum crucible, carefully ascertaining the weight of the quantity so introduced. Let this $= b$. Subject the crucible and its contents to the required heat, and again ascertaining the weight of the precipitate now it is thoroughly dry, let this weight $= m$; then it is evident from proportion that the weight of the whole precipitate, supposing it so dried, $= \frac{a\,m}{b}$.

When the quantity of fluid to be filtered is very small, and the clear liquor is wanted for experiment, it is advisable to moisten the filtre first with distilled water, to compensate for the moisture which it will absorb.

Flasks. Figs. 29, 30, and 31 are of the common form and of white glass; they are principally used for forming solutions in acids, water, &c. The common flasks in which Florence oil is sold are the best that can be procured; they will bear a heat approaching to redness without injury, and always form a serviceable and cheap resource for the experimental Chemist.

Furnace. In the construction of furnaces there is great variety; the following, however, are some of the most useful, but in the processes of modern Chemistry large furnaces are much less called for than formerly.

The *Evaporating Furnace*, or *Sand-bath.* Fig. 32 represents a front section of the furnace; A, the ash-bin; B, the grate; C, part of the flue; E, the sand containing an evaporating dish at F; G, the place of the ascending flue. Fig. 33 represents a vertical section, perpendicular to the former. The other parts correspond; but it is to be observed, the flue C, after running along the front, returns again, and is carried along the back, as at D, before it rises to form the chimney G.

The *Blast Furnace* is variously made, but fig. 34 is on the whole the most convenient. "A is the internal cavity for containing the fuel and crucible, it is slightly bevelled downwards, as in the figure, to allow of the fuel sinking down as the lower part is consumed; B is the flue passing into a hot chamber; C, an appendage particularly useful for drying luted crucibles, or raising them gradually to a proper temperature for the furnace, for roasting ores, and various other purposes; D is the flue connecting it with the vertical chimney E, which, to produce a strong heat, should be 30 or 40 feet high; F F are covers, consisting of twelve-inch Welch tiles, with handles; G, the stoke-hole, through which no more of the fire is seen than what appears between the grate and the bearing bar H, this space is left for the purpose of raking the fire, or occasionally taking out the bars; K is the ash-pit, which is sunk below the level of the ground, and is covered, when it projects at L, by an iron grating." Henry.

The *Reverberatory Furnace.* "Figs. 35, 36, and 37 represent the section and plans of a Reverberatory Furnace. The fuel is contained in an anterior fire-place, and the substance to be exposed to the heat is placed on the floor of another chamber, situate between the front one and chimney. The flame of the fuel passes into the second compartment; by the form of which it is concentrated upon the exposed substance, which is never confined in a separate vessel or crucible, but placed on the floor of the furnace. When reduced to a state of fusion, the melted mass is allowed to flow out through the tap-hole at H. In all three figures, A represents the ash-pit; B, the grate composed of movable bars; C, the door at which the fuel is introduced; D, a door in the side of the chamber for the purpose of inspecting the process; E, the floor of the furnace, which descends and is gradually contracted towards the back part; F, another door, for introducing and stirring the materials; G, the back part of the furnace, immediately under the chimney; H, the tap-hole; I, the chimney." (Henry's *Chemistry*.)

The *Forge*, as used in every blacksmith's shop, gives a very intense heat, and forms a valuable part of every well appointed Laboratory.

The *Assay Furnace* being applied to the purposes of that art only, and but seldom used in experimental research, we refer to the Article on that subject in the *Miscellaneous Department.*

Knight's Portable Furnace is one of the most useful, as it may be applied to a great variety of purposes. It is made of sheet iron, and lined with fire clay. Fig. 38: A is an aperture, with a movable stopper for the neck of a retort in distillation; B is the door; C, another aperture, corresponding to one on the other side, for introducing a porcelain tube if necessary; D is the ash-bin, with a sliding register to regulate the draught.

Aikin's Portable Blast Furnace is formed from the common black-lead crucibles used by the goldsmiths. In fig. 39, the lower piece C is the bottom of one cut off so as to leave a cavity of about one inch in depth. The middle piece or fire-place A is formed from another, and a third is inverted, and placed upon the centre piece at B; a hole is cut for the escape of smoke; the pipe of a pair of double bellows is inserted at F, and from the cavity in the piece C the air passes through six gimlet holes to the fire; on a stand, resting in the bottom of the furnace, a crucible is placed, as seen at X. This furnace, if supplied by the steady action of a good pair of double bellows, produces a prodigious heat, and is certainly one of the most economical and effectual furnaces in the Laboratory. By a slight alteration it may be adapted to the purposes of assaying. See Henry's *Chemistry*, vol. i. p. 446.

Common Crucible Furnace. The same kind of crucible, with a small kind of grate loosely fitted in, so as to give room for a sort of ash-bin beneath, and having a hole, as at A, fig. 40, for the pipe of a pair of bellows, will be found of constant and essential service.

Gasometer. An instrument for containing gases, and, as the name implies, for measuring their volume. Of the common gasometer, fig. 41 represents the vertical section. A is a hollow cylinder of sheet-tin, entirely open at the bottom, and sliding freely up and down between the sides of the fixed cylinder B and the exterior of the gasometer C. D and E are stopcocks at the mouths of the tubes, which run down the sides of the vessel, and, uniting in the centre, reascend to F, thus forming a communication with the interior of the instrument. Water is poured in at the top, and, by inspection of the figure, it is obvious that the water will rise from the bottom P Q, until it reaches the level of the dotted line D E, filling only the space between the cylinder B and the exterior surface of the gasometer; a circular ring of about one inch in breadth. Thus, all communication between the gas in A and the atmospheric air is cut off. By opening either or both the stopcocks, D and E, and pressing down the cylinder A, the air is driven out, and by the same apertures any other air may be introduced. The volume of air contained is shown by the graduated line on the side of the movable cylinder. G, G are weights running on pulleys for counterpoise. F is a cavity, in which it is sometimes convenient to put solid substances capable of abstracting certain impurities from the gas contained in the vessel.

Pepy's Gasometer, or *Gasholder*, consists of a japanned iron or copper vessel, fig. 42. A is the part which contains the gas, and commonly holds six or eight gallons. B is a cistern for holding water, having two tubes opening into it. These tubes, furnished with stopcocks, are seen at C and D underneath the cistern, the middle one, D, reaching nearly to the bottom of the vessel; the other tube C opens into the lower vessel A, but is not continued downwards. In order to fill this vessel with water, the aperture F is closed with its screw; the stopcocks C, D, E being all open, water is poured into the cistern above, which descending through the tubes C and D, forces out the air from E. When the gasholder is nearly full, the stopcock E must be closed, and the small remaining quantity of air will escape through C until the vessel is quite full, when the stopcock must be closed. To fill the vessel with any gas, as oxygen for instance, an iron bottle, containing manganese, is put into the fire, and the stopcocks being all closed, the aperture F is opened, and the end of a tube passing from the iron bottle is introduced. It is obvious that as soon as an evolution of gas takes place from the end of the tube, it will ascend to the top of the gasometer, and the displaced water will escape at F. The tube G is of glass, and opens at top and bottom into the gasometer, and of course serves to show the level of the gas at any time. Bladders may be filled at E, or jars, if placed in the trough over the orifice C; but previously to all such operations the orifice F must be carefully closed. The funnel screws on at B, for the sake of increasing pressure when a bladder is to be filled, or the instrument converted into a blowpipe by screwing a jet on at E.

Gasometer for producing a uniform Pressure. The gasometer, fig. 43, is taken from Biot's *Physique*, and either the same, or one on a similar principle, will be found of great service in many experiments on the gases.

Let a vessel B be furnished with tubes and stopcocks at S, R, and *o*. Let there be a communication by the tube Z (having a stopcock at O) with the vessel A, having apertures at F and T, the former fitted with a stopper, and the latter having a tube open at both ends. This flat top is cemented to the vessel A. Now suppose the cock at O closed, and that the vessel A is filled with water through F, which is then closed with its stopper. If the cocks S and *o* be shut, and those at R and O be opened, the water, descending, will drive the air through the tube at *t*, and this current of air will issue with a uniform velocity; for, by a well known law, it will at all times be subject to the pressure of a column of water, extending no higher than the point H, wherever the surface of the water may be in the vessel A. Of course it must not descend below the point H. The extremity of the tube Z is made to bend upwards in the vessel B, to prevent the air rising through the descending fluid into the vessel A.

To fill this gasometer with any gas, let us suppose the common air all driven out through R, and the vessel B filled with water. Close O and R. Affix a bladder containing the gas to π, which tube descends to the bottom of the vessel at *h*. Open the cocks at S and *o*, and, as the gas enters the vessel B, the water will issue at the orifice *o*, till the cock S be closed. In this state the instrument is extremely convenient for burning combustible gases from jets fixed at R, for the cocks S and *o* being closed, by opening O a uniform current of gas is delivered as before. It will easily be seen that the gas may, if necessary, be transferred to one or more such vessels, as represented in the plate wherein the corresponding letters A, B, F, H, O, &c. represent the same corresponding parts in the first description. This apparatus provides a convenient method for subjecting gases to intense cold or to great heat; for, if the communication be made between R and S, by the tube *t*, this tube may be passed through a furnace or other convenient apparatus, and by the intervention of a third vessel B, or the removing the former one B, the gas may be passed through the tube as often as is required.

Fig. 44 is the outline of a similar apparatus, in which the gas is preserved from the contact of water by passing backwards and forwards through the tube *t*, from bladders at its extremities. Here B is, at first, full of air. By the admission of water and opening the cock at R, a current of air is driven into C, which, compressing the bladder, propels the gas through the tube V V, into the other bladder. By a similar application of the gasometer B, the gas may be driven back again to C, and so on without limit.

The *Graduating Tube* is a taper glass tube, fig. 45, with a capillary orifice. Suppose that it is required to graduate a glass measure into cubic inches, or tenths, or hundredths. The weight of such a given volume of mercury is easily obtained by calculation; this quantity is then carefully weighed into a glass capsule, and from thence either poured or sucked into the tube. The height M, at which it stands in the tube, is then marked with a file, and by successively filling the tube to this mark, and then transferring the contents to the tube to be graduated, marking it at each time, any number of the required degrees may be obtained.

In this process let *s* be the specific gravity of the mercury employed, and as at the temperature 62° F., a cubic inch of water weighs 252,458 grains troy, it follows that if our graduation required were $\frac{1}{100}$ of a cubic inch, we must take a weight of mercury equal to $2,52458 \times s$ grains, to form the standard division upon our graduating tube.

Jars. Of these Pneumatic Chemistry will require an extensive assortment; they are of glass, and of different sizes; some are graduated, some are not: the method for graduating these, is identical with that employed for measures.

Knives. The common pallet knife of the painters, and other similar instruments made of horn or bone.

Lamp. The kinds employed in the Laboratory are the lamp in which spirit of wine is burned from a cotton wick, or from a wick made of a faggot of fine brass wire; figs. 46 and 47. The former is of glass, the latter of japanned tin. Fig. 48 represents Argand's Oil Lamp in its most common form. In this well known and excellent lamp the wick has a circular form, and thus allows a current of air to pass up through the centre of the flame. The combustion is rendered so perfect, by proper management, as to allow of no deposit of lamp black on the vessels exposed to its flame. For effecting solutions in flasks, for distillations in small retorts, and, indeed, for every experiment to be conducted on a small scale, this is an invaluable instrument in the hands of the experimental Chemist.

Professor Daubeney, of Oxford, speaks highly of a portable gas lamp, and such we have seen; but, as yet, this sort of lamp is not in general use.

Lutes and Cements. Lutes are cementing substances applied to the joints of Chemical apparatus, especially retorts and receivers, to prevent the escape of volatile matters. It is sometimes necessary to smear or co the surfaces of retorts or tubes with some such substance.

otect them from the action of a strong fire. Ce-
s are of essential service in the Laboratory to join
en vessels, and to assist in constructing the endless
ty of apparatus employed in Chemical research. A
therefore, of the most useful kinds of each will be
ibed.

t Lute is made of good clay, of which, perhaps,
used by the pipe-makers is the best: it should be
dried,(but, according to Thenard, should not be
ed,)finely powdered, and sifted. It is then to be
ally mixed, and beaten up with drying oil. The
beating it receives, the better is its quality. The
tity of oil is to be such as to make the lute of the
stency of glazier's putty. It resists well the action
rrosive vapours, but, of course, does not bear much
In a closed earthenware vessel it will keep long
ured, which greatly adds to its convenience.

nseed, or Almond Meal, or any coarse farinaceous
ance, if formed into a paste with water, or, what is
etter, dissolved starch, or weak glue, will make an
lent lute: it should be bound round with slips of
tened bladder, or bits of rag. This is, perhaps,
ost convenient lute of any, but its combustibility
its application.

me forms the basis of some valuable lutes and ce-
s. Let a lump of quick lime be partially slaked,
ing once dipped in water, and then suffered to fall
wder: a thin paste formed of this with strong glue,
e white of eggs, is very tenacious, and sets with
rapidity, especially if some more of the powdered
be strewed over it. For joining glass tubes, re-
and receivers, and other such purposes, a rag may
pped in the glue or white of egg, and wrapped round
essel: the lime being applied afterwards.

me and fine brick-dust, formed into a paste with
, will make a cement, having a considerable power
sisting moisture for coarse purposes.

simple and excellent method for joining glass ap-
us, is by soaking slips of bladder in warm water:
ladder then thickens, and if smeared with paste or
of egg, will closely adhere. Linen rag and paste
sometimes, be similarly employed. The cements
ne have this advantage, that they may be applied
tly to any accidental crack: and thus, by careful
gement, the vexation and loss of beginning an
tion anew is avoided. They bear also a consi-
le heat without injury.

e Lute is applied to retorts, or tubes, when it is
sary to subject them to a strong heat, by which
ight otherwise fuse or fall together and lose their
. It is prepared by beating clay with as much
and as can be employed, without destroying the
ity of the mass: old crucibles pounded are better
the sand; and chopped hair, or straw, or tow, must
ded in small quantity. Such a lute is applied to
terior of iron furnaces, to protect the metal from
tion of the fire. The lids of crucibles are cemented
hen required, with this compound. One thing is
tant, that the coated vessel be suffered to dry
ughly, before it is subjected to the action of the

sible Lute is of service chiefly to counteract the
ity of earthen retorts, or to fill up the cracks by
they are too often impaired. The following is
mended for this purpose. (*Repertory of Arts, &c.*
.) "Dissolve one ounce of borax in half a pint of
g water, and add as much slaked lime as will make it into a thin paste. Spread it over the retort with a brush, and, when dry, apply over the whole a lute of slaked lime and linseed oil, beaten till it is perfectly plastic. This becomes dry in a day or two, and the vessel is then fit for use. Stoneware retorts may thus be used several times with safety, (always renewing the oil and lime lute,) whereas, in the common way, and even with the clay and hair lute, they generally crack when cooling, or on being heated a second time."

The following composition is recommended by Aikin for joining on the covers of crucibles, or other such purposes, where it is required to keep the vessels air-tight when hot. "Brick-dust and clay, in fine powder, are to be mixed with a tenth part of glass of borax: when wanted for use, a sufficient quantity is to be mixed with water, so as to be conveniently applicable to the vessels. The heat to which they are afterwards exposed, brings the luting to a state of semivitrification adhering firmly to the crucible."

Parker's Cement, made into a paste with water, soon sets; it will bear a red heat, and may be made air-tight by being brushed over with a melted mixture of equal parts of wax and oil.

Plaster of Paris. Put some water into a capsule, and keep sprinkling the powder into it. This cement may be made air-tight in the same manner as the former, and is still stronger if mixed up with weak glue. It will bear a low red heat.

Fusible Fluxes, for coating tubes, retorts, &c. so as to glaze them, may be made by mixing any clay with one-tenth of its weight of borax; a cream is to be formed with water, which is to be applied with a brush.

Stourbridge Clay, ground to a fine powder, makes with water a lute, capable of bearing a higher temperature than any other English lute.

A sufficient number of lutes have now been described for the Laboratory of the experimentalist: it remains then, under this head, only to mention some of the best cements.

Hard Cement. That which is most extensively employed, is easily prepared by melting together, in an iron ladle, five parts of resin, one of bees' wax, and adding one part of very fine brick-dust or bole earth, or red ochre, or Venetian red. The compound is to be well stirred together; it may be poured out of the ladle upon a greased stone slab, and, while warm, molded into sticks and kept for use. This cement is well adapted for joining glass vessels, or for stopping cracks. It resists moisture, but, of course, is unable to bear heat or the action of spirits and oils.

A still cheaper kind, for inferior purposes, is made of six pounds of resin, one of red ochre, half a pound of plaster of Paris, and a quarter of a pint of linseed oil. A heated iron rod is the most convenient mode of applying these cements, the first especially.

Soft Cement. Yellow wax two parts, turpentine one part, with a little Venetian red to give colour. This cement may be made plastic at any time, by working it a little in the hands, and is extremely convenient for rendering any apparatus air-tight, where heat is not likely to interfere; also for rendering the stoppers of bottles perfectly air-tight.

Glass, or precious stones, may be very firmly united by merely heating them sufficiently to melt mastic, which is to be applied to the whole of the surface of fracture, and the two pieces pressed together so as to leave as little as possible of cement between.

Caoutchouc, or Gum Elastic, is a useful substance when formed into tubes, or it serves to join glass tubes together for the transfer of gases; for this purpose there is a convenient sort manufactured in sheets by Mr. Hancock, Goswell Mews, Goswell-street-road.

The labels are usually affixed to bottles by gum water, but for this purpose isinglass, dissolved in warm vinegar, is preferable.

Pasted Paper. This is a most convenient mode of affixing labels, and also for stopping cracks in apparatus. Mr. Faraday has given a good receipt for preparing it. Take equal parts of powdered gum and flour, and add a little alum, make this into a thin cream with water in an evaporating dish. Keep stirring this mixture over a lamp till it boils, and after it has boiled a few minutes it may be removed, and applied to the paper with a brush. The paper is then suffered to dry, and moistened for use as occasion may require.

Those cements, which are employed for uniting metals, are termed *solders*, and, concerning them, a more particular account will be found in another part of this Work: but as the Chemist must frequently become his own workman, he will have, at times, to experience the great difficulty of making a solder unite with the surfaces of the metals he wishes to join. In Galvanic experiments, few surfaces, which appear to touch, are, in reality, in such contact as to allow of the conveyance of the fluid: hence it is frequently necessary to unite the wires by soldering. Copper and brass wires are prepared for receiving and uniting with common solder, by dipping them into a solution of nitrate of mercury: by this method they are rendered perfectly free from grease, and an amalgam is formed at the surface which materially favours the operation.

Iron Cement, such as is used for joining iron pipes, is not often required in the Laboratory. It consists of sulphur one part, sal ammoniac two parts, iron eighty parts. The iron to be clean turnings in small bits, and the whole to be mixed up with a small quantity of water.

Matrass. See *Flask.*

Measures. The measures of capacity mentioned in the writings of English Chemists, are the wine gallon; its fourth part, the quart; and its eighth, the pint, equal to 28,875 cubic inches. Few modern writers, however, make use of any measure of capacity for gases, except the cubic inch, which forms, undoubtedly, the most Scientific unit.

The following relations are, however, important, as they form part of the Parliamentary regulations enacted in 1825.

The pound Troy contains 5760 Troy grains.

The pound Avoirdupois contains 7000 Troy grains.

The Imperial gallon contains 277,274 cubic inches, or 70000 grains of water. Hence the pint contains 34,66 cubic inches very nearly, or 8750 Troy grains of water.

The cubic inch of water = 252,458 Troy grains.

The cubic inch of mercury = 3425,35 Troy grains.

The standard temperature and pressure for the above being Thermometer F. 62, Barometer 30 inches.

It may be convenient to remember that to convert old measures to the Imperial standard,

Multiply by 0.96943 in corn measure.
Multiply by 0.83311 in wine measure.
Multiply by 1.01704 in ale measure.

And to convert the Imperial into the old measures,

Multiply by 1.03153 in corn measure.
Multiply by 1.20032 in wine measure.
Multiply by 0.98324 in ale measure.

The accurate graduation of measures for gases and liquids, is of great importance to the practical Chemist: and for this purpose a very convenient instrument has been already described. See *Graduating Tube.*

When a jar only partly filled with any air is standing over the pneumatic trough, it is evident that the air within is not under the full pressure of the atmosphere, and therefore has its volume enlarged. To know the actual volume under a mean pressure and temperature, a calculation is necessary; (see *Barometer* in CHEMISTRY;) but supposing a jar to be immersed always to the same depth in the trough, say, for example, one inch; then, if it be first filled with water, and successive equal measures of air be admitted from a smaller vessel, the jar may be tolerably accurately graduated as far as pressure is concerned; and in this case, it is evident that the divisions will decrease in distance from each other, proceeding from the top of the jar. Had the jar been graduated by equal volumes, as a tube, it must have been sunk to such a depth in the water, that the fluid within and without might be on a level before any correct estimate of its contained air could have been obtained.

Mortars. Of this utensil there should be in the Laboratory several kinds. A large bell-metal one, of Wedgewood's ware, several sizes, fig. 49. A small iron one with a turned cavity. These are so well known, as to require no further description. Fig. 50 represents what is called a diamond mortar. It is used to abrade substances, without allowing any particle to fly off in the operation. This mortar is made of hardened steel. The pestle is *a*, a solid cylinder turned so as to fit the tube *b* accurately, which tube is exactly fitted to the cavity *c* of the mortar.

Fig. 51 represents a section of the agate mortar and pestle, employed for reducing hard mineral substances to an impalpable powder, for analyses after they have been broken down in the diamond mortar.

Muffle. Fig. 52, a sort of small oven made of crucible clay, for the protection of cuppels when placed in a furnace.

Phials form, of course, a part of the furniture of the Laboratory. There is a kind with a glass cap fitting closely over the common stopper: very convenient for æther, acids, and other liquids producing volatile or noxious vapours.

Pneumatic Trough. A vessel calculated to contain water or mercury for the confinement of gases in Pneumatic Chemistry. The water trough may be thus constructed, (fig. 53.) A B is a rectangular vessel of tin or of tinned copper plate, in a wooden frame, and standing on four legs. At the part C the depth of the trough is not more than $2\frac{1}{2}$ inches, and on this part the jars stand when in use. The part D, however, is 10 or 12 inches deep, with a shelf E whereon to rest the jars during the operation of filling; and to facilitate this purpose, there are small holes having inverted funnels beneath; under which the beak of one or more retorts may be placed.

The mercurial trough may be formed by hollowing out a piece of close-grained wood: but the most complete are made of cast iron, and sold at the shops of the Philosophical instrument makers.

Proof, a sort of small flask, into which a curved tube is fitted by grinding. They are plain, fig. 54, or tubulated, fig. 55. For obtaining small quantities of gases, they form a convenient apparatus.

Receiver. See *Distillatory Apparatus*.

Retort. See *Distillatory Apparatus*.

Sand-bath. A vessel containing heated sand, into which retorts and flasks are immersed for evaporation or distillation. They thus receive an equable temperature, and are protected from the immediate action of the fire. The sand-bath may be fitted to the top of a portable furnace; or, if large, may be heated by a flue, and thus form a part of the range of furnaces in the Laboratory.

Scissors and Shears, of various sizes, for cutting wire, plates of metal, &c. &c.

Sieves of muslin and hair, of different degrees of fineness.

Soils. Davy's instrument for the examination of, fig. 56.

Syphons: for drawing off the clear liquor from above precipitates.

Tubes of glass, porcelain, platinum, iron, caoutchouc, &c. &c.

Tubes graduated: are generally about half an inch in diameter, and about a foot long: they are used in delicate experiments on gases, and are commonly divided into parts of a cubic inch, by a method already explained under *Measures*.

Tube, dropping or sucking. This very useful little instrument has been already noticed, fig. 18. At the lower end is a very small orifice, which being introduced into the clear fluid from which a precipitate has subsided, by suction with the mouth at the upper orifice, the bulb of the tube may be filled with fluid, and on closing the orifice with the tongue, the tube may be removed without the loss of one drop of the fluid. Thus, by repeating the process if necessary, a precipitate may be obtained nearly free from all supernatant fluid, without occasioning any disturbance in it, and the objectionable use of a filtre is avoided.

Tubes of Safety. To guard against the effects of absorption on the one hand, or expansion on the other, the tubes of safety are employed. Figs. 57 and 58 represent the two kinds. Suppose the tube, fig. 57, to be fitted by passing through a cork or cement into the tubulature of a retort or Woulfe's bottle; and that so great a pressure from the expansion of gaseous matter took place, as to endanger the bursting of the vessel. In this case the bulb C is about one-third filled with mercury, and as the pressure takes place upwards, some portion of the gas will escape; but the mercury retaining its place, will suffer no return of atmospheric air to the vessel.

Next, suppose that in a retort to which the tube, fig. 58, is affixed, a condensation of the gaseous contents takes place, so that absorption may be commencing at the beak of the retort, the cold fluid entering would infallibly break the vessel. But the bulb containing mercury, as in the former case, though differently arranged, will suffer some of the atmospheric air to ascend through the tube, and thus restore the equilibrium.

Fig. 59 represents a Woulfe's bottle, having a tube of safety, formed of a small glass tube, passing through a cork, and dipping half an inch below the surface of the fluid in the bottle

Tube transferring: is not in very general use, but is, nevertheless, a convenient instrument, and is thus described by Dr. Thomson:

"It is often necessary to transfer determinate quantities of gas from the water trough to the mercurial trough. This must be done without introducing any water along with the gas, except what may exist in the gas in this state of vapour. This is done with the greatest facility, by means of the tube represented in fig. 60, which was first used, we believe, for the purpose in question, by Mr. Cavendish. This is a glass tube open at both ends: but one of the extremities is bent round, and is drawn out into a fine capillary bore. The tube is graduated into 100th parts of a cubic inch, and the degrees should be made as conspicuous as possible. A good method is to fill the lines after they have been cut in the glass with black or red sealing-wax. When we want to transfer a given bulk of gas from the water trough to the mercurial trough, we fill this tube with mercury, and shutting the end *b* with the finger, we introduce the end *a* into a glass jar standing over water, and filled with the gas to be transferred. On removing the finger from the extremity *b*, the mercury falls down, by its weight, into a vessel placed at the bottom of the trough to receive it, and the gas enters by the capillary extremity *a* to supply its place. When the gas admitted into the tube amounts to the quantity desired, (half a cubic inch for example,) we shut the end *b* with the finger again. We then withdraw the tube from the water trough and wipe it dry. The end *b* is now to be placed uppermost, and the end *a* introduced under the bottom of the glass jar (filled with mercury, and standing over the mercurial trough) destined to receive the gas. On removing the finger, the weight of the mercury in the tube forces out the gas. When it has all made its way into the destined test glass, we remove the tube; and we may, in the same way, introduce an additional quantity of any other gas, till we have made up the intended mixture."

Tunnels, of pewter, glass, and Wedgewood's ware. Glass tunnels employed for filtering, should have raised ribs of glass running from the top towards the lower orifice for the escape of the liquid. Without this contrivance, the moist paper adheres to the sides of the glass, and the process is very materially retarded. Sometimes glass rods, or bits of straw are placed between the paper and the glass to answer the same purpose.

Weights. See *Measures*.

Woulfe's Apparatus is represented in fig. 61. By an inspection of the figure, it will be evident that if A be a tube through which gas is passing from a retort, for the purpose of being absorbed by the same or different liquids in the two tubulated bottles: the vertical tube in the centre will prevent any liquid being forced from the second bottle into the first, in case of absorption; the gas which does not combine with the liquid in the first vessel, will pass into the second, and if not there absorbed, may pass into a third similarly disposed, or to a pneumatic trough by the tube B.

For further information, consult Faraday on *Chemical Manipulations, and an Explanatory Dictionary of Apparatus and Instruments employed in the various Operations of Chemistry*, Lond. 1824. Also Aikin's *Chemical Dictionary*, 2 vols. 4to.

Introduction.

Arrangement.

(1.) It may be reasonably expected, that something should here be premised with regard to the Arrangement that will be adopted in the following SYNOPSIS OF CHEMICAL SCIENCE. The difficulties that immediately present themselves on commencing such a task, are well known to every Chemist. We might, perhaps, safely shelter ourselves under the authority of some well-known writer, and adopt the system which he has made use of. This, however, is not our intention; but we shall lay before our readers an arrangement which to us seems better adapted to the nature of this Work than any that we could thus select; not that we are confident of its being intrinsically better for all purposes, or that it ought to be generally adopted; for we are fully convinced, that as the Science itself is only in a progressive state, and by no means advanced to maturity, future discoveries must greatly change, and may indeed altogether overturn those fundamental positions upon which all our existing Systems rest. We possess among the English, German, and French writers, several excellent general Treatises on this subject; but the fact of no two of these writers having adopted a similar arrangement, must show that great diversity of opinions exist upon the subject; and that the voice of universal consent has not called any one Scheme to the post of preeminence; and therefore cannot condemn a writer for arranging the Facts of this Science in whatsoever order may seem to him best fitted for explaining its Laws and Principles.

There is, however, a sort of presumption in favour of a Synthetic method of describing, first, all the Simple bodies, and then the Binary compounds, and next the Ternary, and so on; to be derived from the fact, that Thomson, Thenard, and Berzelius, the three best Systematists, have all, more or less, adopted it. Our reason for departing from a plan sanctioned by such high authorities is this; that as the properties of a Simple substance, which it is the Chemist's province to investigate, are, in fact, mainly developed in its power to enter into the combination of more complex bodies, the Principle of such an arrangement is perpetually and necessarily violated. Thus, for instance, one of our most able writers professes to describe the Element Iodine; and, according to his System, Iodic Acid, a Binary compound, ought to appear in a different part of his Work; whereas he finds himself compelled to describe the Acid in treating of the properties of the Simple base. This is no solitary case; the properties of the more Complex substances are so constantly starting up before us as characteristics of their Elements, that the same evil pervades every portion of such a Classification. We admit that it has a less appearance of Philosophical arrangement to describe any one Elementary substance, and then to pursue it through all its more complex forms, for the production of Proximate Elements; but we think that by such a method the properties are more readily studied in connection with each other, leaving less probability of repetition or omission. All must have experienced the difficulty of hunting through the properties of one substance, described in several parts of the same Work.

Whatever be the truth in these particulars as referring to a complete Code of Chemical Science, we feel persuaded that the Plan which we have here adopted is better suited to a Synopsis like the present, which must be limited to a moderate magnitude, and having its peculiar characteristics as a Work of reference only. We profess to give a Summary of the properties of each known body; and it is of obvious importance that these should be arranged in such a manner as to be most ready of access; but to extend the utility of our pages we give also a series of references to direct the Student, who may wish to pursue any research more in detail, to all that is valuable on the subject.

(2.) As it happens with regard to some substances, that either subsequent discoveries or differences of opinion on points of theory have introduced more than one name for the same substance, we have in such cases affixed the Synonymes to the head of each subsection. The Chemical Symbols for the Simple, and also for many of the Compound bodies, will be found from the Tables in the Appendix; but may, in some cases, be conveniently introduced before.

Generally speaking, we refer the more complete description of any compound to its second appearance in this Treatise: thus if A and B unite to form a Proximate Element, we mention the combination under the Section describing A; but reserve the description of the substance to the Section on B, for the sake of becoming acquainted also with the ordinary properties of the Element B; but this rule is not quite invariable. At times we find ourselves compelled to speak of the action of a substance, to which the Scheme may hitherto not have conducted us. In extenuation of this apparent dereliction from the just laws of System, we would urge that no reader is in reality so little acquainted with the Chemical Elements as not to know them by name when the word may occur to him.

We have found it convenient also not to insert the Atomic Weights of bodies in the text, except for some specific purpose; but all these, as well as the Specific Gravities, will be given in a tabular form in the Appendix.

(3.) In pointing out to the Student those Works from the perusal of which he will derive the greatest advantage, we may be frequently understood as making our acknowledgments to those Writers to whom we feel under the greatest obligation for the assistance they have afforded us in arranging this Treatise.

As the most Elementary Work, we recommend the *Conversations on Chemistry*, in two volumes 8vo.; a much larger and more Scientific Work also in two volumes, by *Dr. Henry*. There has also been recently published a very good Work in one volume 8vo., by *Dr. Turner;* and Nicholson's *Chemical Dictionary*, with additions by *Dr. Ure*, will be found to contain much useful matter.

The four great Systems of *Thomson*, *Murray*, *Thenard*, and *Berzelius*, are all Works of first-rate merit. The first abounds in valuable facts and extensive references; the second is a Work containing much of the Philosophy of Chemistry, written in a very continuous and pleasing style; M. Thenard has given extensive generalizations, which are of the greatest importance; and the last edition of the System of Berzelius, seems not unworthy of the reputation of that most distinguished and indefatigable Philosopher. The original is in Swedish; and we conclude that it is not yet completed, as we are in possession of only the first five half volumes of a German translation, which is published at

PART I.

CHAPTER I.—IMPONDERABLE AGENTS.

INTRODUCTION

(5.) It has been usual in Systems of Chemistry to enter rather fully into the History and Effects of the four substances or properties, (be they which they may,) the names of which are comprised in our first Part. This was more especially the case with the first and third; and was a necessary consequence of the method in which these Sciences had been studied. This necessity, however, no longer exists; each of the four, *viz.* Caloric, (Heat,) Light, Electricity, and Magnetism, having vindicated to itself a separate rank among the Sciences: and each has very properly formed the subject of a separate Treatise in this *Encyclopædia*. We name them here, not for the purpose of repetition; not with the design of entering at large upon the general doctrines of each of these Sciences; but only to mark their connection with *Chemistry*, and to describe the *Chemical Effects produced upon the Elementary Molecules of Matter by their Influence:* viewing them strictly in the light of *Agents;* means employed to effect Chemical purposes. Future researches may, it is true, show that some one or other of these forms the Spring and Principle of Chemical Affinity; or, on the other hand, it may appear that Chemical Affinity is the influential agent for the developement of some of these Physical Properties: but, in the uncertainty that at present exists, we consider the arrangement we have adopted as best calculated to elucidate the principles of our Science.

§ 1. *Chemical Agency of Caloric.*

Caloric.

(6.) Caloric is the term made use of to designate the cause of Heat; the comparative absence of Caloric, or its presence in a less degree, we call Cold: these are but terms of ordinary language, and not very precise in their meaning. The real nature of Caloric is at present unknown. By some it is supposed to be actually a fluid substance; by others, only a property of matter. Should the former supposition be correct, we need only observe, that its tenuity is such as to have hitherto eluded all efforts that have been made to prove that it possesses any gravitating power. Under either view, therefore, we are justified in calling it one of the Imponderable Agents. The numerous and highly important Physical Properties that it exerts upon all material Bodies have already been examined in our Treatise upon Heat. In Art. (108.) of that Treatise we have marked out what we conceive to be the just boundary between the effects of Caloric upon Physical and Chemical Science; or, in other words, we have separated its effects into those which take place upon the Integrant Molecules of Matter, from those which take place upon the Constituent ones. The latter alone fall within the scope of this Treatise

It is obviously essential to the sort of action that we now suppose, that there should be present dissimilar elementary Molecules in the Chemical sense of the word; these we are to consider either as combined or uncombined. If the Molecules be combined, Caloric may produce Decomposition; if uncombined, and the Molecules be conveniently disposed for the operation to take place, Caloric may effect their union.

(7.) The cases of Chemical Decomposition effected by Heat alone, are, perhaps, neither very numerous nor very distinctly marked. The general operation of increased Heat upon all matter tends to convert it successively from the Solid to the Liquid, and from the Liquid to the Gaseous form. But should no extraneous matter be present, decomposition does not frequently take place. It is true, that where Molecules chemically dissimilar are in union, and these are very unequally affected physically by the action of Caloric, decomposition may readily ensue. To select a familiar instance, let any alloy of Mercury, with some metal of difficult volatility, be heated beyond the boiling point of Mercury; the Mercury will rise in vapour, and break from its Chemical combination with the less volatile metal. This is, however, in great measure a Physical operation; for in the commencement of our experiment the dissimilar Molecules of the two metals are united by their Chemical Affinity, with a force surpassing that by which the Molecules of the more volatile metal tend to separate, and to assume the Gaseous form. But, by further accession of Caloric, this latter force increases to such an extent as to overpower the former one, and decomposition ensues.

(8.) Nevertheless there are instances in which, as far as we can judge, the Physical effects upon the dissimilar Molecules of a compound body are equal; and yet, by increase of Temperature, decomposition is produced. For instance, the gas called Protoxide of Chlorine (Euchlorine) undergoes decomposition, and its Gaseous Elements separate, upon exposure to a very moderate increase of Temperature.

(9.) On the other hand Caloric, or its effect Heat, seems to be a powerful promoter of Chemical combination. It is well known that many Elementary bodies, when placed in contact, and heated, enter into Chemical union. But here also it is difficult to say precisely how much of this effect is truly Chemical and how much Physical; how much is due to the change of Molecular affinity produced by the Heat, and how much to the state favourable to union, arising from a change in the Physical constitution of the bodies acted upon.

(10.) Hitherto we have limited our remarks to the action of Caloric either upon two or more dissimilar bodies not in union, or upon one compound body. But the case which is of more frequent occurrence to the Chemist is, when either a compound body and an Elementary body, or two, or even more, Compound bodies are acted upon simultaneously. In these cases the practical effects of Caloric are very considerable. Whatever be the original state of the Chemical Affinities between the Molecules concerned, Heat will very often modify these Affinities, and facilitate the production of new combinations. In this view Caloric is one of the most important agents in the hands of the Chemist. It frequently aids us in forming combinations, which otherwise we are unable to effect; it promotes solution, in part possibly, by being itself a great antagonist to Solidity; and it seems almost always to be the spontaneous concomitant of all violent degrees of Chemical action.

§ 2. *Chemical Agency of Light.*

(11.) The only part of the history of Light which we conceive to belong to the subject now before us, is its *agency* in promoting Chemical composition or decomposition. For its general properties see the Treatise on LIGHT.

Scheele noticed some of the decompositions produced by Light, and examined the conditions necessary to the success of the experiment. Oxygen, when held by a light affinity, may be separated by this agent; and this extends to metallic oxides of that kind even when combined with an acid. Thus Scheele, having evaporated a solution of gold to dryness, again dissolved the salt in distilled water, and placed the solution in a glass-stopper bottle. The bottle was then exposed to the sun's rays, and in a fortnight the surface became covered with a pellicle of reduced gold. (*a.*) Mrs. Fulhame also, in her *Essay on Combustion*, states, that a piece of silk, which had been dipped in a solution of gold, was exposed to the sun's rays and kept rather moist; it was at first yellow, then became green, then purple, then showed spangles of gold; and at the expiration of an hour the whole piece of silk was covered with a film of metallic gold. Another piece of silk was similarly treated, and put into a dark place, in which it remained three months without undergoing any change save the acquisition of a brownish tint. Silver also in solution was reduced by the action of Light, while in the dark it underwent no alteration. Many very amusing experiments of this nature may be seen in Mrs. Fulhame's *Essay*. (*b.*)

(12.) In nitric acid the oxygen is retained by a feeble degree of affinity. If a bottle containing this acid be exposed to the sun's Light, it first becomes yellow, then orange, by the separation of a part of its oxygen. But if the same bottle be quite full and closed with a glass stopper, no such decomposition can take place from the mechanical obstacle opposed to the escape of the oxygen. (*c.*) Berthollet found that a bottle so exposed to the sun's rays, and provided with a bent tube to convey the gas to a Pneumatic trough, produced a considerable quantity of oxygen in a very few days. (*d.*)

(13.) If a piece of paper moistened with a solution of nitrate of silver, or if a portion of the precipitated muriate of silver (which is a white powder) be exposed to the sun's rays, a very few minutes are sufficient to change the colour almost black. It is believed, that in these changes the acid is frequently removed, wholly or in part, as well as the oxygen from the metal. Berthollet contrived that this colorific process should take place under water; and he found that a portion of the acid had in fact separated from the oxide and remained in the water. (*e.*)

(14.) Scheele proved that it was to a true Chemical agency on the part of Light, and not to its Heating power, that these effects were to be attributed. For this purpose he exposed the same substances which he had found to change so readily, but in phials covered with black paint. The phials became very hot, but even in several days' exposure no Chemical effect was produced upon the substances within. (*f.*) This fact was further confirmed by Berthollet. Rumford, however, adduced experiments in opposition to this doctrine, and endeavoured to show, that the effects produced were due to the Heat alone. He obtained a partial degree of reduction, by exposing pieces of silk, which had been dipped in metallic solutions, to the Light of a candle. He produced the same effect by placing small pieces of charcoal in a tube with some solution of gold or silver, and then exposing the whole to the Heat of boiling water, the metals were reduced on the surface of the charcoal. (*g.*) The first experiment we conceive proves only that the Light of the taper tended, in some degree, to produce the same effect which the sun's Light would have accomplished more speedily and completely. The second case also was proved to be fallacious by Berthollet, who showed, from the gas evolved, that the decomposition had been caused by the direct action of the charcoal. (*h.*)

Promotes combination.

(15.) Having thus adduced instances of Decomposition, produced by the action of solar Light, we must now show that it possesses, in a very marked degree, the opposite property in certain cases of determining combination.

Mr. Dalton remarked when Chlorine and Hydrogen gases were mixed together, Light had a material effect upon the rate of the Chemical combination which resulted. Thus in a feeble Light the union took place but slowly, but if the mixed gases were exposed to the direct rays of the sun, the combination was so rapid as to be frequently attended with an explosion. (*i.*) MM. Gay Lussac and Thenard observed the same fact, and found that it even held good with the compound hydrogenous gases when mixed with Chlorine. (*k.*)

Berthollet had previously shown that if a solution of Chlorine in water were exposed to the sun's Light in a flask, provided with a bent tube to collect the gaseous product, oxygen was evolved. (*l.*) The Chlorine decomposed the water, uniting with the hydrogen to form muriatic acid, and hence the escape of gaseous oxygen. Chlorine and carbonic oxide are not readily brought to combine, even under considerable elevation of temperature, but by exposing the mixture to solar Light the union is effected.

(16.) To solar Light then we must allow a considerable power of Chemical action, but we shall find that the different parts of the solar beam differ greatly in this power. Scheele first remarked that when the solar spectrum was cast upon a piece of paper, impregnated with muriate of silver, it became black much sooner in the violet than in the other coloured rays. (*m.*) Senebier repeated this experiment, and estimated the comparative powers thus. The same tint produced upon the muriate of silver by 15 seconds' exposure to the violet ray, required for its production 23 seconds in the purple ray; 29″ in the blue; 37″ in the green; 5½ minutes in the yellow; 12 minutes in the orange; and full 20 minutes in the red ray. (*n.*) Sir H. Englefield found that the blue ray had a greater power than the other rays in communicating the luminous property to Canton's Phosphorus. Seebeck found that when a mixture of Chlorine and Hydrogen gases was exposed to the solar Light, under a red glass, the combination took place but slowly, but that under a blue glass the union was instantaneous; with several other similar facts. (*o.*)

(17.) The existence of calorific rays beyond the extreme limit of the visible red ray of the spectrum, suggested the possibility of a similar set of Chemical rays beyond the opposite, the violet end. This inquiry seems to have been pursued by Dr. Wollaston and M. Ritter simultaneously. They both found that there was a set of Chemical rays of greater refrangibility than those of Light and of Heat. Ritter came fully to the conclusion that, besides the visible rays of the spectrum, there were two other sets of invisible rays: one of which being less refrangible than any of the luminous rays, was found beyond the red end of the spectrum, having a greater calorific power than the colorific rays, and tending also to promote oxidation: the other set of invisible rays being more refrangible than the colorific rays, was found beyond the violet end of the spectrum, being inferior to the colorific rays in heating power, and tending to the separation of oxygen from its combinations. (*p.*) Dr. Wollaston made use of muriate of silver also, and arrived at a similar conclusion. He employed also guaiacum, which changes from a yellow to a green colour by exposure to Light; and this, from the absorption of oxygen, as is proved by the process succeeding better when the gum is placed in oxygen gas. There was, however, this peculiarity, that the change was promoted at the violet end of the spectrum, while in the red extremity the yellow colour might be restored. This fact, then, is hostile to the universality of Ritter's law. (*q.*) Berard amply confirmed these experiments; he divided the spectrum into two portions, and then concentrated the rays of each portion with a lens. The part from the red to the green produced a brilliant Light, but the muriate of silver remained in it for more than two hours quite unaltered. The part from the green to the violet inclusive did not by its concentration produce a very vivid Light, but blackened the silver in less than ten minutes. Hence we learn that the deoxidating power of the rays decreases very rapidly in passing from the violet to the red end of the spectrum. (*r.*)

(18.) It would appear, also, that there is an analogous difference in the Chemical action of artificial Light produced from different sources; for Mr. Brande has stated that the Light produced by the combustion of oil gas, coal gas, or olefiant gas, even when concentrated so as to produce a considerable degree of Heat, effects no change on the muriate of silver, nor yet on a mixture of Chlorine and Hydrogen; but that the Light from charcoal, ignited by the voltaic battery, speedily colours the muriate and unites the gases. He could obtain no Chemical action from the Light of the moon. (*s.*)

Some other experiments of Ritter in the paper formerly mentioned are very curious, and the report of MM. Berthollet and Biot, upon Berard's experiments, is well worthy of examination. (*t.*)

Affects crystallization.

(19.) Some experiments of M. Chaptal tend to prove that the process of crystallization is influenced by the presence of Light. He found that when a number of capillary crystals were shooting up the sides of a vessel containing a saline solution, the effect took place only on that side of the vessel that was illuminated. He was thus able to cause the crystals to form on any one side, and by placing a skreen against the vessel the line between Light and darkness was distinctly marked by the limit of the crystallization. This phenomenon was most easily observed in metallic salts. (*u.*)

(20.) "The operation of Bleaching affords another example of the Chemical changes which Light is capable of producing. Colour is in that case removed, and this depends equally on the transfer of oxygen, the colouring matter of the thread receiving that principle probably from the decomposition of the water with which the substance to be bleached must be supplied. This formed the old method of bleaching; and the substitution of the Chlorine in the new mode, establishes this theory of the changes of which the operation consists.

"Even the processes of animated nature are influenced by the Chemical agency of Light. 'Organization, sensation, spontaneous motion, and all the operations of life (says Lavoisier) exist only at the surface of the earth, and in places exposed to the influence of Light; and without it nature itself would be inanimate.' Its operation in vegetation is strikingly exemplified in the adaptation of plants to particular climates. Those which grow under a clear sky, and an intense solar light, are in general more pungent, odorous, and aromatic, than those which are placed under the opposite circumstances; and plants which are the natives of a warm climate will not grow or produce their fruit in situations where they are less exposed to its genial influence. The artificial exclusion of Light from vegetables, giving rise to the process named Etiolation or Blanching, affords another proof of its action on vegetation. The plant always extends its branches towards any opening at which light may enter; and if this be closed, and another opened in a different situation, it changes the direction in which it was shooting, and still turns towards the Light; and in this way, as M. L'Abbé Tessier has shown, plants may be made to grow in any direction. If kept in perfect darkness, they become feeble, succulent, insipid, and of a white or yellowish colour, while, if transferred to a situation where they enjoy the solar rays, they regain their green colour, and become vigorous. These changes from the exclusion of Light appear to be owing to the accumulation of oxygen in the plant, as, under its influence, this principle is disengaged from their leaves, derived probably from the decomposition of water, and perhaps of other compounds subservient to vegetable nutrition. According to the experiments of Tessier and Decandolle, the Light emitted by a lamp gives even a green colour to the leaves, though less deep than that from the light of day. The Light of the moon has a similar effect. (*v.*)

(21.) "Nor are animals exempt from the influence of this important agent. Deprived of it they suffer nearly the same changes as vegetables do, and the darkness of their colour is in general greater according to the intensity of the Light to which they are habitually exposed. Insects which live underground are usually of a light shade; the animals of the Arctic regions are almost all pale or white, while those belonging to the tropical countries are distinguished by the variety and brilliancy of their hues. Even in Man we trace a gradation of colour proportioned nearly to the climate in which he resides." (*w.*)

References from (10.) to (21.) inclusive.

(*a.*) Scheele's *Essays on Air and Fire*, p. 83. (*b.*) Fulhame, *Essay on Combustion, &c.* p. 151. (*c.*) Kirwan, *Note to his Translation of Scheele's Essay, &c.* p. 230. (*d.*) *Jour. de Phys.* xxix. p. 82. (*e.*) *Chemical Statics*, vol. i. p. 147. (*f.*) *Essay on Air and Fire*, p. 96. (*g.*) Rumford's *Philosophical Papers*, p. 341. (*h.*) Berthollet, *Chem. Stat.* i. p. 149. (*i.*) Dalton, *Syst. Chem. Phil.* p. 300. (*k*) *Mém. d'Arcueil*, vol. ii. p. 347. (*l.*) *Jour. de Phys.* xxxix. p. 81. (*m.*) *Essay on Air and Fire*, p. 91. (*n.*) Senebier, *Mémoires Physico-Chimiques*, tom. iii. p. 199. (*o.*) Seebeck, Nich. *Jour.* xxiv. p. 220. (*p.*) Ritter, Nich. *Jour.* v. p. 255. viii. 214. (*q.*) Wollaston, Nich. *Jour.* viii. p. 293. (*r.*) Berard, Nich. *Jour.* xxxv. p. 256. (*s.*) Brande, *Phil. Trans.* 1820, p. 11. (*t.*) Berthollet and Biot, Nich. *Jour.* xxxv. p. 257. (*u.*) Chaptal, *Jour. de Phys.* xxxiii. p. 297. (*v.*) *Mém. de l'Acad. des Sciences*, 1783, p. 155. (*w.*) Murray's *Chemistry*, vol. i. p. 561.

§ 3. *Chemical Agency of Electricity.*

(22.) According to the Principles already proposed, this Section will be devoted to an account of the *Chemical effects of Electricity*; including those which are produced by the application of the Voltaic Pile, as well as those which proceed from the common Electrical Machine. That these two instruments only produce different modifications of the same great Physical Agent we have already explained; and therefore for the future, when we speak of the Electrical agency by which any Chemical change is to be effected, we would be understood to refer to an operation producible either by ordinary, or by Galvanic Electricity, though much difference may exist as to the actual fitness of these respective modifications of Physical force, with reference to the purpose intended.

Electricity existed for many years as a Science, previous to the discovery of its intimate relations to Chemical Affinity, and this discovery did not take place until Voltaic Electricity had become known to the Philosophers of the present Century. Galvani's discovery of what he termed Animal Electricity, which was in fact the Electricity of the contact of dissimilar Elements, took place accidentally in 1791. It was succeeded by about ten years of active research made by the Philosophers of all Europe; but as the great problem which they investigated with so much zeal, was the necessary conditions of the probable theory of muscular contraction produced by this species of Electricity, no immediate profit accrued to Chemical Science. At length, in 1800, Volta, by a fair system of reasoning upon the effects of Metallic contacts, was led to construct the Pile. His end was fully answered when he had obtained a series of most interesting Electrical effects highly important to the Theory which he was labouring to establish. The history of this discovery was communicated to Sir Joseph Bankes, who laid the letter before Messrs. Nicholson and Carlisle. (*a.*) By these gentlemen the experiments of Volta were repeated and verified: they discovered the positive and negative Electricities of the opposite ends of the Pile; and accidentally stumbled upon the great discovery of the first Chemical decomposition effected by Electricity. They had formed a part of their circuit by water, and observing small bubbles of gas to be disengaged, apparently from the wires in the water, they found that this gas had the smell of Hydrogen. The important remark was not lost upon these experimentalists, who, pursuing the research, fully demonstrated the decomposing power of the Pile. They found that at one wire Hydrogen Gas was evolved, while the other wire became oxidated; and by employing wires of Platinum they obtained Oxygen and Hydrogen Gases from the two wires respectively, and in such proportions as to form water. Such was the origin of this most important series of discoveries. (*b.*)

Mr. Cruickshanks, an eminent Surgeon at Woolwich, immediately verified these discoveries, and added to them that of the reduction of metals from their solutions, and the decomposition of the Neutral Salts. Cruickshanks also invented the Trough. Dr. Henry of Manchester decomposed the Nitric and Sulphuric Acids; and also resolved Ammonia into its Elementary Constituents. At length Sir H. Davy commenced that splendid series of researches which have tended more than those of any other individual to explain the Electrochemical relations of the molecules of bodies; and have not been surpassed in acuteness of investigation, or brilliancy of result, by those of any individual that ever lived, if we except the sublime discoveries of the great author of the *Principia*. It were unjust not also to mention the valuable contemporary researches made in Paris by Humboldt, Gay Lussac, and Thenard; though we do not enter upon any minute historical description of them in this place, but refer our readers to the Treatise on GALVANISM.

Identity of Agents.

(23.) For the best proofs of the identity of ordinary and Galvanic Electricity we are mainly indebted to Dr. Wollaston. The question has been long agitated; and perhaps to some, may not even yet appear to have been satisfactorily decided. The sensation, however, produced upon the human frame is substantially the same, whether from the Leyden Jar, or from the excited Voltaic Pile. The rapidity of communication is the same in both cases. The conducting powers of all bodies are identical to both fluids. The spark is in both cases visible when the discharge takes place through a thin stratum of air. The Pile in activity will charge a Leyden Jar either positively or negatively, according to the Pole with which the connection may be established. The Electrometer serves as a measure of Tension for both instruments. And the Chemical changes which may be produced by developing the Polarities of elementary or constituent molecules of bodies, are the same in kind, whichsoever agent be employed. (*c.*)

Most useful combinations.

(24.) Before we proceed to the actual Chemical agencies of the Pile it may be well to mention those Voltaic arrangements which are best adapted to the purposes intended. This we say with reference chiefly to selection, for as the actual construction of Galvanic Apparatus more properly belongs to the general Treatise on that subject, to it we refer our readers.

(25.) The simple Galvanic circle consists of three more or less perfect conducting substances. It may be formed either of two perfect conductors and one imperfect conductor; or of two imperfect conductors with one perfect conductor. These terms were introduced by Sir H. Davy, in whose Work various arrangements of both sorts may be found (*d.*) But as the effects produced by any simple Galvanic Circuit are feeble; especially with reference to Chemical action, it is usual to form compound Galvanic Circuits or Batteries. These consist simply of the reiteration of a number of simple alternations. The metals and the liquids are arranged in various forms, as Troughs, Piles, or Spirals. In practice Copper and Zinc are the metals usually employed; producing a combination of great energy at the least expense.

(26.) For igniting or fusing Metallic wires, or in other words, for producing great Heat by generating a very considerable quantity of Electricity in a short time, so as to produce Heat in its passage through a conductor comparatively perfect, plates of large surface are required. But for producing Chemical Decomposition large plates are not necessary: the number of the plates is, however, of essential importance; they may be small, but they must be numerous. The *Couronne de Tasses* of Volta is an excellent arrangement for Chemical purposes: but on the whole the Battery we can most strongly recommend, should consist of plates from four to six inches square, arranged after Dr. Wollaston's plan in Wedgewood Troughs.

Charges.

(27.) Though water and saline solutions are sufficient to excite the Chemical action of a Battery, yet weak acid liquids are most efficacious. For Chemical purposes the acid may be used in a highly dilute state: Mr. Singer, who made many experiments on this subject, recommends one part of Sulphuric Acid with two or three of Nitric Acid, and from forty to sixty parts of water, as an efficacious and enduring charge.

Where long-continued action is required, without great intensity, a solution of common salt, with the addition of a little Muriatic Acid, forms an economical and sufficient charge. Those effects which are purely Electrical are best developed by a charge consisting of a weak saline solution; or even of spring water only.

Chemical action.

(28.) We now arrive at that which is the legitimate object of this Section; *viz.* the Chemical action of the Pile. If any compound body, which is itself a conductor, or which can be made even partially so, be placed between two wires connected with the Poles of the Battery, so that the substance itself shall form a part of the Circuit, the Elementary molecules of that body will undergo certain changes in their forces of Polarity, and in many cases to such an extent as to overcome the Affinity which formerly bound them together in Chemical combination.

For example, let two Platinum wires from the opposite Poles of the Battery be placed at any distance from each other in the same vessel of water; bubbles of Gas will be disengaged at the extremities of each wire; the quantity issuing from that part of the water in contact with the wire proceeding from the Negative Pole of the Battery is, in volume, double of that issuing from the other wire which constitutes the Positive Pole: and if these gases be collected, as they easily may by inverting test tubes filled with water over them, the former is found to be Hydrogen, the latter Oxygen Gas. Now these are known to be the just constituents of water, and if the gases be again mixed and exploded by the Electric spark, water is reproduced without any residuary matter.

If the wire forming the Positive Pole be of copper, or any oxidable metal, the oxygen never assumes the gaseous form, but unites with the metal so as to produce a metallic oxide.

If in a similar manner the wires be introduced into a strong solution of Sulphuric or Phosphoric Acid, Oxygen Gas will rise from the Positive Pole and the inflammable Element will collect round the wire connected with the negative Pole.

(29.) The following is found to be the general Law of these decompositions, *viz.* that the non-metallic bodies, (sometimes thence called Electronegative,) Oxygen, Chlorine, Fluorine, Iodine, and Bromine, with all Acids, are found at the Positive Pole of the Voltaic Circuit, while the Electropositive non-metallic Bodies, (combustibles of some writers,) the Metals, Alkalis, Earths and Oxides, in short all bases, tend to the Negative Pole or surface.

(30.) The following singular extensions of these properties were discovered by Sir H. Davy in 1806 and 1807. If the Polar Wires do not dip into the same mass of water, but into separate vessels of that fluid, having a connecting metallic wire between them, the decomposition still takes place; Hydrogen Gas is evolved from the one wire, and Oxygen from the other. The same takes place if the connection between the two vessels of water be made by moist fibres of Cotton, Ammianthus, or any other conducting substance.

To understand these interesting experiments of Sir H. Davy; suppose two Agate cups marked P and N to denote the Poles of the Battery with which they were connected; Positive and Negative respectively. Sulphate of Potash, or Soda, was placed in N and distilled water in P; the connection between the two cups was established by moist fibres of Ammianthus. The Acid passed over to the cup P, and the solution in the cup N, which was at first neutral, became alkaline. A converse experiment was made by placing the saline solution in P, and distilled water in N. In this case the water became alkaline, and pure Acid remained in the cup P.

In another experiment when Nitrate of Silver had been placed in the cup P, the Ammianthus leading to the cup N was coated with a film of metallic Silver; thus showing that an actual and substantial passage of the Element took place along the connecting substance.

The same results obtain if a third cup M, containing pure water, be placed between P and N, so as to form a part of the connecting circuit, while the water remains pure, though the Acid and the base have both been transmitted through it.

Again, let the three cups be arranged as before; having Sulphate of Potash in N, a weak solution of Ammonia in M, and pure water in P. In this case, to arrive at the cup P the Sulphuric Acid must pass through a free Alkali for which it has a very strong Affinity: yet in five minutes this was effected with a Battery of one hundred and fifty pairs of four-inch plates. Thus the ordinary forces of Affinity were suspended or overpowered by that of Electrical Polarity. In the same way, strong Acids were made to pass through strongly alkaline solutions, and alkalis through strongly acid liquids, without entering into combination.

It was by reasoning upon these facts, that Sir H. Davy contrived to apply the decomposing power of the Pile to the exhibition of the bases of the alkalis and alkaline earths, and thus arrived at a series of results as novel as they were important. (*e.*)

(31.) Strictly speaking, there can be no Electro-chemical action upon a substance that is a Nonconductor; and yet some adventitious circumstance may induce a sufficient degree of conducting power to bring the Elementary molecules of the substance within the reach of the Electrical action, so that their Polarity may be affected and decomposition produced. For example, Glass is a nonconductor, and yet where Electrochemical experiments are made in glass vessels, a slight decomposition of the surface will sometimes be manifested by the setting free of a portion of its alkali. In this case the water or liquid forms the mean of communication for a sufficient Electrical power to the molecules of glass immediately in contact with it.

(32.) Among the most usual Galvanic experiments are those in which metallic wires or leaves are either fused or burned by the discharge of a Battery. The metals are all comparatively perfect conductors; but the circumstance of their becoming heated at all by the Electrical discharge, seems to us a proof that they are not strictly so. By a perfect conductor we should understand a body which would instantaneously allow the passage of any quantity of Electricity without reference to the superficial magnitude of the conducting body itself. A perfect conductor in this sense is, however, unknown; the metals which are the best conductors, suffer certain effects, which bear some constant ratio to the quantity of Electricity transmitted, and to the quantity of metallic surface along which it passes. The first and most obvious of these effects, is the developement of Caloric. Thus wires are heated, or even fused, by the Voltaic as by the Electric discharge. So far this is only a Physical operation; but when the discharge is very powerful, the metals undergo combustion, and are oxidated. Now whether this Oxidation be simply the effect of their Elevation of Temperature in a medium affording Oxygen, so that the same effect in kind and quantity would be produced by an equal intensity of Heat howsoever excited; or whether the Heat evolved during the Electrical Transit be at all more favourable to this Chemical combination, by adding a sort of determining force, no experiments have yet ascertained.

We might, therefore, at present, be justified in regarding the burning of metals by Galvanism, merely as a case of Chemical combustion arising out of the ordinary Physical application of Heat to a combustible body. The most powerful Battery that has ever been constructed for the fusion and combustion of metals, is that of Mr. Children, with which most splendid results were obtained. The description of this instrument and its powers may be seen in the *Phil. Trans.* (*f.*)

(33.) The conditions upon which the ignition or combustion of metallic wires depends, are totally different from those which influence Chemical decompositions. It is generally understood that in the Voltaic Battery the Intensity of the Electricity depends upon the number of plates; and that the Quantity evolved depends upon the superficial magnitude of the plates. Chemical decompositions, as we have already remarked, depend upon Intensity of action, and, therefore, require a great number of plates which may be very small; but the Calorimotive effect upon metals, seems to arise from Quantity; and, therefore, for these last-mentioned purposes, the number of the plates is not so important as their magnitude. And as in these cases it is desirable that the Electricity should be evolved with great rapidity, the charge of dilute Acid may be advantageously employed of a greater strength than is required for Chemical purposes. All this is stated as fact deducible from experiment, without reference to any particular Theory of the action of the Pile.

Ratio of Powers.

(34.) It is a curious and important inquiry to ascertain the ratio which the number and superficial extent of the plates in a Battery, bear towards the effects of different kinds produced by that Battery. On this subject the following remarks by Sir H. Davy, are important. "MM. Gay Lussac and Thenard have announced that the power of Chemical decomposition increases only as the cube root of the number of plates; but their experiments were made with parts of Piles of a construction very unfavourable for gaining accurate results; and in various trials, made with great care in the Laboratory of the Royal Institution, the results were altogether different. The Batteries employed were parts of the great combination, carefully insulated, and similarly charged; arcs of Zinc and Silver presenting equal surfaces, and arranged in equal glasses filled with the same kind of fluid, were likewise used; and the tubes for collecting the Gases were precisely similar, and filled with the same solution of potassa. In these experiments, ten pairs of plates produced fifteen measures of Gas; twenty pairs in the same time produced forty-nine; again, ten pairs produced five measures; forty pairs, in the same time, produced seventy-eight measures. In experiments made with arcs, and which appeared unexceptionable, four pairs produced one measure of Gas; twelve pairs, in the same time, produced 9.7 of Gas; six pairs produced one measure of Gas; thirty pairs, under like circumstances, produced 24.5 measures; and these quantities are nearly as the squares of the numbers.

"It would appear from the experiments of Van Marum and Pfaff, confirmed by those of Messrs. Wilkinson, Cuthbertson, and Singer, that the increase of power of Batteries, the plates of which have equal surfaces, is as the number. I found that ten double plates, each having a surface of a hundred square inches, ignited two inches of Platina in wire of one-eightieth of an inch; twenty plates, five inches; forty plates eleven inches; but the results of experiments on higher numbers were not satisfactory; for one hundred double plates, of thirty-two square inches each, ignited three inches of Platina wire of one-seventieth, and one thousand only ignited thirteen inches, and the charges of dilute Acid were similar in both cases.

"The power of ignition for equal numbers of plates, seems to increase in a very high ratio with the increase of surface, probably higher than even the square; for twenty double plates, containing each two square feet, did not ignite one-sixteenth as much wire as twenty containing each eight square feet, the acid employed being of the same strength in both cases.

"Numerous circumstances are opposed to the accuracy of experiments made with high numbers or very large surfaces; the activity of combinations rapidly diminishes, in consequence of the decomposition of the menstruum used; and this decomposition is much more violent, the greater the number and surface of the alternations; the vapour rising likewise, when the action is intense, interferes by its conducting power, and the Gas by its want of conducting power; and when series containing above five hundred double plates are used, unless the insulation is very perfect, there is a considerable loss of Electricity; thus the great Battery of two thousand double plates belonging to the Royal Institution will scarcely act by its true Poles, when arranged on a floor of stone, and requires not merely the insulation of porcelain, but likewise of dry wood; and when arranged on a stone floor, it is hardly possible to walk near any of the approaching series without receiving shocks. In cases of the ignition of wire, the cooling influence of the substances in contact, and of that part of the chain not ignited, interferes most when small quantities of wire are employed, and with feeble powers; and hence the effect is at first in a lower, and then in a higher ratio than the number, when the whole range is small, as in the experiments above stated. If there is an imperfect connection in any of the series, a great diminution of power is the consequence. If one plate is corroded or covered with more oxide than the rest, there is a general loss of effect. If copper is substituted for Zinc, or Zinc for Copper, in a single series the result is similar; and I find that a Platina wire, introduced in the place of an arc of Silver and Zinc, in a series of thirty, diminished its power of producing Gas so much, that it was equal only to that of four." (*g.*) Consult also references (*h.*)

Theories.

(35.) To examine the different Theories which have been proposed in order to account for the origin of those Phenomena which are termed Galvanic or Voltaic, falls not strictly within the scope of this Treatise. It may, however, be necessary for us to state in what manner it seems connected with Chemical Affinity, especially as some have supposed all Chemical Affinities to spring from Electrical action; whilst others, on the contrary, have asserted that all Electrical Phenomena are essentially accompanied by Chemical changes, thus referring those Phenomena to the mutations which take place among the Elementary molecules of Bodies. Whether the Electrical Polarities of the molecules of matter be or be not the cause of Chemical Affinity, is a question which the Chemist is deeply interested in resolving.

Volta, who laboured assiduously and successfully in this field, supposed that Electricity was developed solely by the contact of dissimilar metals. The fluid with which the Pile is charged, he regarded only in the light of a conductor. It seems true that the mere contact of two metals is sufficient for the evolution of Electricity; for if a plate of Copper and a plate of Zinc be made to touch each other, both being affixed to insulating handles, the Copper, after their separation, is found charged with resinous, and the Zinc with vitreous Electricity. The same, however, has been recently found to take place with two discs of the same metal when they are of different temperatures before their contact. In these cases no Chemical change is apparent; though it is possible, and even probable, that some oxidation may take place to a slight extent. In this Theory of Volta all the Chemical changes which manifestly attend the Electrical action, are, *as causes*, disregarded.

Dr. Wollaston became the most direct opponent of the views of Volta, and in an admirable Memoir, published in the *Philosophical Transactions* for 1801, he advanced numerous arguments in support of a contrary explanation of the case. The substance of Dr. Wollaston's Theory consists in supposing the Chemical change to be the primary action; as, for instance, the oxidation of the Zinc, where plates of Zinc and Copper are employed; and that the developement of Electricity is a consequence resulting from thence.

The Theory of Sir H. Davy, which is now more generally received, acknowledges both sorts of action already noticed. It admits the disturbance of the natural Electricities upon the contact and subsequent separation of dissimilar bodies, and does not consider that a Chemical change is essential to the commencement of Electrical action. But it was proved by experiment, that for the continuance and accumulation of Electrical action, Chemical changes in the Elements of the Pile are indispensable. Sir H. Davy traces this mixed operation by supposing that by the contact of the Zinc and Copper plates in the Pile, all the former become Positive, and all the latter Negative; that by means of the conducting fluid interposed, all the vitreous Electricity is enabled to accumulate at one end of the Pile, and all the resinous fluid at the other. Such is the primary and momentary action; but to produce a repetition of these effects, so as to promote the continuous action of the Pile, he considers the Chemical change as perpetually tending to restore the Electric equilibrium that has been thus disturbed. This takes place by the Electronegative Elements, Oxygen, Acids, &c. passing to the Zinc plate, while the Electropositive Elements, the Bases, Hydrogen, &c. go to the Copper surface, restoring, momentarily, the Electric equilibrium in both cases, and thus preparing the metals for a new effort of the Electromotive force. On these points consult references (*i.*)

(36.) Whatever Theory be adopted with regard to the primary developement of Electrical Action in the Pile, it becomes a matter of convenience to form some system which may unite in one view the effects as such; in order that we may employ it as a practical assistant in submitting bodies to Voltaic Electricity as a Chemical Agent. For this end it is quite immaterial which of the Theories already mentioned be admitted. In fact, the explanation which we are about to recite is to be considered not as an assertion of the actual laws which govern the molecular Affinities of substances, but only as a convenient mode of representation, a sort of illustration; it may be the true one in its most strict sense, or it may not; but in either case we may safely employ it as a law by which to regulate the methods, and foretell the results of our experiments.

Of such explanations the most clear was given by Grotthus, and first published in Italy. We subjoin the substance of it, as given in M. Thenard's Work, though it is almost *verbatim* the same with that of the original author as republished in the *Annales de Chimie*, (*k.*) because it gains an additional authority from having passed through the hands of that able Systematist. (*k.*)

If we place between the two Polar wires of a Pile in activity, any substance which is capable of undergoing decomposition by that Pile, immediately all the elementary molecules in each compound atom placed between the Positive and Negative Poles, undergo Polarization; that is to say, their natural Electric fluid is decomposed, and some of the Elementary molecules becoming Positive, tend towards the Negative Pole; while others becoming Negative, tend towards the Positive Pole. Suppose there to be only five compound Atoms between the two Poles, and that each Atom should be composed of two Elementary molecules; let A represent the Positive molecule and B the Negative molecule in the first Compound Atom; also let A′ be the Positive molecule, and B′ the Negative molecule in the second Compound Atom, and so on: the arrangement which will then result is shown in the following diagram:

the bottom of the vessel was uniformly covered with crystals.

Such is the scanty display of facts which we are able to produce in connection with this branch of our subject, but we think they are sufficient to show that Magnetic action does exert some influence on molecular attraction.

References from (22.) to (40.) inclusive.

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PART II.

CHAPTER I.—*General Physical Properties of Ponderable Matter.*

(41.) The Properties of Matter which we profess to examine in this Treatise are those that are strictly Chemical. But it must not thence be inferred that we have no business with the Physical Properties of bodies, for several of those marks by which a Chemist distinguishes one substance from another are, strictly speaking, Physical Properties. Such as Hardness, Specific Gravity, Elasticity, Colour, &c. To investigate all these fully is a part of the province of General Physics, and several of these properties form the basis of all Mechanical Science. In this preliminary introduction we shall as briefly as possible mention those Properties which are essential to the understanding of future Sections, entering at the same time rather more fully upon such details as form a portion of the operations of practical Chemistry.

Physical Properties

(42.) *Magnitude* is a Property belonging to all substances, and need not be made more intelligible by verbal definitions: let it only be remembered that it refers to space alone. Magnitude may be Linear, Superficial, or Solid; in which latter case it is usually spoken of under the term *Volume*. *Divisibility* is a Property of Matter having reference to Magnitude. Mathematically speaking, Matter is divisible *ad infinitum*, but the practical or mechanical divisibility of Matter is limited by our powers of handling or viewing minute objects. Hence it is that the Chemical divisibility of Matter greatly exceeds that which can be effected mechanically: for by dissolving a solid substance in any appropriate menstruum we may very greatly dilute the solution, and still be able to prove by reagents that every portion of the solution, however minute, contains also some portion of the original Solid. The limit to this also seems to be fixed by the powers of our organs of vision, &c. But in this case the extreme minuteness of that portion of solid matter which has been separated from the original mass, and thus indirectly again recognised, almost surpasses our conception.

That Property of Matter about which much has been written under the name of *Impenetrability of parts*, is, in fact, the same thing as the Property of being touched and felt, by which we are convinced of the existence of substances. Generally speaking, two substances cannot exist in the same space, and this is all that is meant by the property of Impenetrability; but the existence of the Property itself, speaking with mathematical rigour of Matter in its natural state, seems to be at least doubtful. It is supposed that no substance is absolutely solid, and the experiments with metallic alloys, in which great condensation frequently takes place, as well as the solution of solid masses of metals or salts in liquid menstrua, without proportionably adding to the volume of the mass, goes far to support the mathematical view of the case. Impenetrability exists if we speak of any one given substance only, and it must exist with reference to all Matter if we possessed it in an absolutely solid state; but as this is never the case, we cannot assert it of all heterogeneous bodies with reference to each other.

It would appear that all substances are *Compressible*; some to a great extent, as the Aeriform Fluids; some scarcely at all, as the Liquids and Solids.

Elasticity is also a term of frequent occurrence among the Physical Properties of bodies: it is defined to be that Property by which bodies that undergo compression return to their former state upon the removal of that pressure. It has not been so done, but some limitation ought to be made, as to the manner in which

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and of course less on the summits of high mountains than in the plains below.

(48.) In matters of great delicacy when Solids are concerned, and in all cases when aeriform matter is in question, the Specific Gravities of bodies are supposed to be taken *in vacuo;* and at some given temperature; as, otherwise, the dilatations or contractions produced by Heat would greatly interfere with uniformity of result.

Proceeding upon these principles; if W be the Weight of any mass of matter, S its Specific Gravity, g the force of Gravity at the latitude in which the experiments are made, and W′ the Weight of an equal volume of water, at the standard temperature which in England is usually taken at 60° Fahrenheit, or sometimes 62° Fahrenheit,

$$W = g\,W'\,S.$$

Here it is to be remarked, that W, W′, S, and g, are not absolute quantities, but abstract numbers, each referring to some assumed unit.

In France, it is usual to adopt for the standard Temperature that at which water has its maximum density; and from the constitution of the French System of Weights and Measures, the *Gramme* Weight consists of one cubic *Centimetre* of Distilled Water at that temperature. If therefore V be the number of cubic *Centimetres* in the mass, V is also the Weight in *grammes* of the volume of water equal to that of the substance. And V S becomes the actual Weight of the same volume of any other substance whose Specific Gravity is S.

Should it be required to find the value of W′ for any given volume of water; W′ = 252,458 V Troy Grains; Thermometer 62° Fahrenheit; Barometer 30 inches; where V refers to English Cubic Inches: because at that Temperature and Pressure, one Cubic Inch of Distilled Water weighs 252,458 Troy Grains, according to the latest examination.

(49.) The following General Theorems are of constant service to the practical Chemist.

Let W be Weight, V Volume, and S Specific Gravity.

Then, generally, $W \propto V\,S,$

$$\therefore S \propto \frac{W}{V}, \text{ and } V \propto \frac{W}{S}.$$

Let there be two substances mixed, or combined, providing only that no condensation take place.

Let W_m, W_d, and W_l, be the Weights of the mixture, the denser, and the lighter bodies respectively.

Also let S_m, S_d, and S_l, be their Specific Gravities respectively.

And V_m, V_d, and V_l their volumes respectively.

(50.) Then $S_m = \dfrac{W_d + W_l}{V_d + V_l}.$

(51.) Or $\quad = \dfrac{W_d + W_l}{W_d\,S_l + W_l\,S_d} \cdot S_d\,S_l.$

which is the usual formula, but in practice it is more conveniently represented thus

$$S_m = (W_d + W_l) \div \left(\frac{W_d}{S_d} + \frac{W_l}{S_l}\right).$$

(52.) Also $V_d = \dfrac{S_m - S_l}{S_d - S} \cdot V_m.$

(53.) And $V_l = \dfrac{S_d - S_m}{S_d - S_l} \cdot V_m.$

(54.) Also $S_d = \dfrac{S_m\,V_m - S_l\,V_l}{V_d}.$

(55.) And $S_l = \dfrac{S_m\,V_m - S_d\,V_d}{V_l}.$

(56.) If these formulæ be applied to the case of Atmospheric Air, S_m becomes = 1, because in all questions relating to aeriform bodies, the Specific Gravity of Atmospheric Air is made the unit of the scale to which S_l and S_d are referred. From all the above formulæ g has disappeared, because it is usual to consider the force of Gravity unity.

(57.) These things being premised, we need only advert to one other Property of Matter which also is general in its effects, or operations. It is this, that whether matter exist in the solid, the liquid, or the gaseous form, it dilates by the application of Heat, and contracts when Caloric is abstracted. By this property the Solids are least affected, the Liquids rather more so, and the aeriform substances possess this Property to a very great extent. From their Physical constitution it is obvious that this must be the case; for since the molecules of all Gases and vapours are in so active a state of mutual repulsion, that their volume at all times depends upon the pressure to which they are subject, if we suppose an equilibrium between that pressure and the elastic force of the Gas, any accession of Caloric, which, as is well known, increases the repulsive force, will enable the aeriform Fluid to expand itself, and to occupy a larger volume.

The case of water, which has its maximum density at 40° Fahrenheit, and of those metals which expand during the act of solidification, does not justly form an exception, for all these effects are dependant upon a new arrangement of the molecules which takes place during the process of crystallization.

(58.) It may be convenient to note the general formulæ for the expansions of all bodies by accessions of temperature.

Let V′ be the volume at any temperature t'; and V″ be the volume at temperature t''; where t' and t'' are counted from the point of melting ice. Also let K be the true cubic dilatation for each unit of volume, (in terms of V,) and for each degree of the thermometer to which t refers.

Thus, generally, (HEAT, 35.) $V'' = V' \cdot \dfrac{1 + K\,t''}{1 + K\,t'}$,

which formula applies to Solids, Liquids, or Gases.

(59.) But since in some Tables of dilatations the linear dilatations only are given, let this = k, then in this case,

$$V'' = V' \cdot \frac{1 + 3\,k\,t'' + 3\,k^2\,t''^2 + k^3\,t''^3}{1 + 3\,k\,t' + 3\,k^2\,t'^2 + k^3\,t'^3}.$$

(60.) And it has been shown (HEAT, 35.) that in Solids where at a distance from their fusing points the dilatation is very small, we may make $K = 3\,k$, and employ the formula in Art. (58.); or as a still more simple, though less rigorous, expression, we may use this

$$V'' = V'\,\{\,1 + K\,(t'' - t')\,\}.$$

of 15 inches, occupy a larger space than in the other experiment, and the mercury will only rise, let us suppose to *d*. But let it be remembered that the attenuated air in the narrow tube always occupies exactly the space which the whole occupied under the ordinary atmospheric pressure. Now this space is in the one case the cavity *b c*, and in the other *b d*. Hence it clearly follows, that the cavity *c d*, which is the difference between these, is equal to the bulk of the solid matter in the sand. Now by marking the number of grains of water held by the narrow tube *b e* on a graduated scale attached to it, we can find at once what is the weight of a quantity of water equal in bulk to the solid matter in the sand, and by comparing this with the weight of the sand in air, we have its true Specific Gravity.

"As some porous bodies, such as Charcoal, hold much condensed air within their pores, and may, probably, retain this property in some degree even when in powder, the chance of error arising from this source is obviated by comparing the dilatation which takes place under different degrees of pressure—under 10 inches and 20, for instance, or under 7½ and 15.

"The Specific Gravity of Charcoal is generally estimated as under 5, but by this process the powder of Charcoal exceeds that of the Diamond. The Specific Gravity of Mahogany is 1.06, but of Mahogany sawdust 1.68. That of Wheat flour 1.56, and of pounded Sugar 1.82. Of Salt 2.15, agreeing with the common estimate. Volcanic ashes 4.4, being equal to that of some metallic ores."

Corrections. (65.) Should it be necessary to introduce these very minute corrections, which depend upon the temperature of the substances or liquids employed, the formulæ for this purpose may be seen in M. Biot's *Physique*, vol. i. p. 426, though we cannot devote the space requisite for their introduction into this Treatise.

Solids absorb Gases. (66.) Substances which are usually called Solid, but which like Charcoal contain numerous pores, are capable of condensing within those pores very considerable quantities of Gases: but to this property we shall advert when we have entered more fully upon the description of aeriform fluids.

Properties that belong to Liquids.

Liquids. (67.) Of the extensive catalogue of Properties that has been recited as belonging to Solid Bodies, few only will be found to apply to those Substances which exist in the Fluid State.

Tenacity. In *Tenacity* the Fluids may be said to differ slightly, as there is a difference in the magnitude of the drop that may be formed by each when falling from the mouth of a Phial: and the quantities which will issue from small orifices under given pressures are found to be variable. This circumstance, however, may also be explained by attributing to each different degrees of their characteristic Property Fluidity.

Volatility. Some Fluids are of easy *Volatility;* others are not volatile at all under any processes to which we can submit them; though analogy and experiment would unite in leading us to suppose that all substances in nature are capable of being rendered fluid, and of being also volatilized by the application of a sufficient degree of heat. *Vide Treatise on* HEAT, Art. (65.) &c. And it is to be remembered, that in practice some substances, such as the fat oils, take fire, and are consumed upon a sufficient elevation of temperature: so that the universality of the law seems here to be interfered with by the presence of another phenomenon. The exception is, however, only apparent, for the fat oils are capable of regular distillation in vacuo.

Circumstances connected with the evolution of vapour, and its passage through the fluid, produce the phenomenon of *Ebullition*. *Vide Treatise on* HEAT, Art. (73.) &c. The temperature at which fluids boil, or pass into the state of vapour, frequently forms a part of the Chemist's researches, and ought always to be stated among the physical properties of every fluid.

(68.) For a long time it has been questioned whether liquids were compressible, and water was the substance upon which experiments were made. The Florentine Academicians were the first to devise a process which by its result seemed to prove that water was compressible to a slight extent: the researches of Professor Œrsted and of Mr. Perkins have decided this point satisfactorily. By a pressure of 2000 atmospheres, Mr. Perkins reduced a mass of water to $\frac{8}{9}$ of its original volume.

(69.) As might be expected, the Specific Gravity of Liquids forms an important feature in their Physical History. Water is made the unit of the scale to which they are referred as in the case of solids. The mode usually employed for obtaining equal volumes of the two substances to be compared is very simple: the weight of the water, which is contained by a small bottle capable of being accurately closed, is compared with the weight of an equal volume of liquid obtained by filling and weighing the same bottle.

Let W_w and W_f be the weights of the water and of the liquid respectively, then the Specific Gravity

$$S = \frac{W_f}{W_w}.$$

And for greater simplicity, the small bottle or flask is sometimes made to hold exactly 1000 Grains of Distilled Water, and a constant counterpoise is provided for the empty bottle; so that when it is filled with any other liquid, the weight that is required in addition to the counterpoise to produce an equilibrium, represents at once the ratio borne by the liquid to 1000 grains of distilled water; or, in other words, the Specific Gravity of the Fluid.

(70.) It is evident, however, that the rule above given produces only an approximative result. For, in the first place, both the water and the fluid must be referred to some fixed standard of temperature, to obviate the effects of dilatation. In France, this standard point has been judiciously placed at the maximum density of water, which is about 40° Fahrenheit, but in this country 62° Fahrenheit is usually considered the standard point. In the next place, the dilatation of the bottle should be allowed for by calculation. The experiments also should be made in vacuo; or else reduced by calculation so as to obviate the errors arising from their being made in air and moisture. And lastly, the Barometric Pressure should not be overlooked.

It would be easy to insert formulæ which afford these corrections, but in practice they are seldom resorted to, and the limits to which we must here confine ourselves, only permit our referring those who may wish for further information on the subject to M. Biot's *Physique*, tom. i. p. 399.

(71.) We have already adduced in Art. (58.) a general formula applicable to the Dilatations of Liquids by the Effect of Caloric; but since it always happens pressure; and the other, the ratio of such weights for all the different gases, that is their specific gravities, referred to the weight of any one among them as a unit. For this purpose Atmospheric Air has been employed, calling its weight unity in the Series.

On the general principles of Specific Gravities, if we have the weight of a volume of dry gas and of an equal volume of dry atmospheric air, at a given temperature and pressure, the specific gravity of the gas equals the weight of the gas divided by the weight of the air. But before we enter upon the practical processes for obtaining the Specific Gravity of a Gas, we must become better acquainted with certain other properties of aeriform Fluids.

For the Specific Gravities of the gases see Table No. 1, and consult References (*c.*), (*d.*), (*e.*), (*f.*), (*g.*)

Compression and Elasticity.

(76.) A pure and dry gas is capable of being mechanically compressed when confined in a close vessel, and upon the removal of the pressure, the aeriform fluid returns to its original volume. And when air is confined in a bent tube and loaded with different weights of mercury, the spaces into which it is compressed are found to be inversely as those weights. But the weights are the measures of the elasticity, therefore the elasticity always varies directly as the space occupied by the air.

The density varies inversely as the space, and therefore the elasticity of air varies directly as its density. (Mariotte's law.)

Volume.

(77.) Hence if V be the original volume of a gas under a pressure p, (usually expressed in inches of mercury in the Barometer,) and V′ its volume under a pressure p',

$$\frac{V}{V'} = \frac{p'}{p}, \quad \text{or } V = V' \frac{p'}{p}.$$

This formula is employed whenever we have the volume of a gas $= V'$ under a known pressure p', and wish to ascertain its volume under some other pressure p: in this case V is obtained from the above equation.

Example. Having 100 cubic inches of gas at Barometer 28, what is this equivalent to under the standard pressure of 30 inches?

$$\text{Here} \quad V' = 100 \quad p' = 28 \quad \text{and } p = 30,$$

$$\therefore\ V = 100\ .\ \frac{28}{30} = \frac{2800}{30} = 93.333.$$

(78.) If the air or gas be confined in a tall jar or tube standing over mercury, so that the pressure cannot be naturally equal within and without the jar, and thence the air becomes dilated.

Let the length of the column of gas in the tube $= x$; let the total height of the column of mercury and gas above the surface of the fluid in the trough $= h$; the altitude of the Barometer $= p'$; then the true volume at that pressure,

$$V' = \frac{x}{p'}\ .\ \left\{p' - (h - x)\right\};$$

and V′ may be reduced to V, if required, by formula in (77.)

(79.) And should a similar reduction be required for gas standing over water, since p' refers to a pressure made by mercury, the preceding formula will become

$$V' = \frac{x}{p'}\ .\ \left\{p' - \frac{h - x}{13.5}\right\};$$

and this also may be reduced to the standard pressure p as the preceding.

(80.) The weight of a given volume of any gas (at Barometer 30, Thermometer 60° Fahrenheit) = V (in cubic inches) × Specific Gravity × .305 grains Troy, (the weight of a cubic inch of dry atmospheric air.)

(81.) The weight of a given volume of air or gas varies as its density (49.), and therefore as the pressure to which it is submitted. Hence if we have the weight of a given volume of air at a given pressure, it is easy to ascertain, by proportion, the weight of a similar volume under any other pressure.

$$\text{Generally,} \quad \frac{W}{W'} = \frac{p}{p'} \text{ and } W = W'\ .\ \frac{p}{p'}.$$

Example. If 100 cubic inches of atmospheric air, at Barometer 28 inches, weigh 28.466 grains Troy, what will a similar volume weigh when the Barometer is at the standard altitude?

$$\text{Here} \quad W' = 28.466 \quad p = 30 \quad p' = 28,$$

$$\therefore\ W = \frac{30}{28} \times 28.466 = 30.5 \text{ nearly};$$

30.5 grains being the weight actually admitted at present on the experiments of Sir G. Shuckburgh.

(82.) But it is also known that all substances undergo a change of volume by Heat, and that this operates upon gases to a very considerable extent. It has been shown (HEAT, 34.) that if V be the volume of any substance at 32° Fahrenheit, and V′ its new volume when heated, t the degrees that it is heated above 32°, and K the cubic dilatation of the unit of mass for each degree of Fahrenheit,

$$V' = V.\ (1 + K\,t).$$

Hence if we know the volume of a gas V at 32° Fahrenheit, we can learn its volume V′ upon its being heated any number of degrees; for it has been proved by Dalton and Gay Lussac, that K, the cubic dilatation of all gases, is $\frac{1}{480}$ of the original volume, at 32° Fahrenheit, for each degree that they are heated.

Example. Let it be required to know what will 100 cubic inches of gas, at 32° Fahrenheit, become in volume when heated to 60° Fahrenheit.

$$\text{Here} \quad V = 100 \quad t = 28 \quad \text{and } K = \frac{1}{480},$$

$$\therefore V' = 100\ .\ \left(1 + \frac{28}{480}\right) = \frac{50800}{480} = 105.83 \text{ cubic in.}$$

(83.) But it has also been shown (HEAT, 35.) that the volume at any other temperature may be introduced into the formula without having recourse to the volume at 30° Fahrenheit; and this is a case of more frequent occurrence than the former.

For if V be the volume at 32° Fahrenheit, V′ that at temperature t', and V″ that at temperature t'', we have from the general theorem, calling K the cubic dilatation as before,

$$V' = V\ (1 + K\,t')$$
$$V'' = V\ (1 + K\,t'').$$

Hence by division we have

$$\text{generally,} \quad V'' = V'\ .\ \frac{I + K\,t''}{1 + K\,t'},$$

$$\text{or} \quad = V'\ .\ \frac{480 + t''}{480 + t'} \text{ for Fahrenheit only.}$$

Example. Let it be required to calculate what 100 cubic inches of gas, at temperature 50° Fahrenheit, would become, if heated to 60° Fahrenheit,

$$\text{Here } V' = 100\ .\ t' = 18 \quad t'' = 28 \quad \text{and } K = \frac{I}{480}.$$

Generally, $V'' = V' \cdot \frac{1 + K t''}{1 + K t'}$

$$= 100 \cdot \frac{508}{498} = 102.008 \text{ cubic inches.}$$

(84.) And since air, or gas, is frequently confined in vessels of glass or metal, which also change their absolute capacity by change of temperature, it is desirable to be able to compute the variations arising from this cause. For this we may employ the general formula given in Art. (71.)

(85.) Let it be required also to introduce into the formula last referred to an expression which may provide for simultaneously correcting the volume for any change of barometric pressure from p' to p'' during the experiment.

Let p' and p'' be the barometric pressures at the temperatures t' and t'' respectively: then, by Art. (77.) we have

$$V'' = V' \cdot \frac{p'}{p''} \cdot \left\{ \frac{1 + t'' \theta}{1 + t'' K} \cdot \frac{1 + t' K}{1 + t' \theta} \right\},$$

which gives us the true volume due to the pressure p''.

(86.) And if further we wish to reduce this to the standard altitude of 30 inches, we have from (77.)

$$V \text{ (the volume at standard altitude)} = V'' \frac{p''}{30}.$$

(87.) Let us next consider how the *weight* of a gas is made to vary by change of temperature, *i. e.*

Having the weight of a given volume of gas at a given temperature, required the weight of the same volume at some other temperature.

Generally, if V' and V'' be any two volumes of gas, at temperatures t' and t'' above 32° Fahrenheit, which volumes are both V at 32° Fahrenheit; the weights of any given volume of the gas being W' and W'' at the temperatures t' and t'' respectively.

Then, by (82.) $\quad V' = V(1 + kt')$,

and $\quad V'' = V(1 + kt'')$,

$$\therefore V' : V'' :: 1 + kt' : 1 + kt''.$$

But the weights $\propto$ as the densities which $\propto$ inversely as the volumes.

Hence $\quad W' : W'' :: 1 + kt'' : 1 + kt'$,

and $\quad W'' = W' \cdot \frac{1 + kt'}{1 + kt''}$.

Example. If 100 cubic inches of gas, at temperature 50° Fahrenheit, weigh 50 grains, what will an equal volume of the same gas weigh at 60° Fahrenheit?

Generally, $\quad W'' = W' \frac{1 + kt'}{1 + kt''}$;

here $\quad W' = 50 \quad t' = 18 \quad t'' = 28$;

$$\therefore W'' = 50 \cdot \frac{1 + \frac{18}{480}}{1 + \frac{28}{480}} = 49.015 \text{ grains.}$$

(88.) It is frequently required to apply both the last corrections to a quantity of gas obtained in some experiment; hence

Having a given volume of gas under a given pressure and temperature; required the new volume when both pressure and temperature are changed.

Part II.

This Problem may be solved at two steps: first ascertaining the change from temperature by (83.), and then the change by pressure by (77.); but it is neater to embody both in one formula.

For this purpose call the original volume, temperature above 32° Fahrenheit; and pressure; V', t', and p', respectively.

And let t'' and p'' be the new excess of temperature above 32° Fahrenheit and the new pressure; while V'' is the new corrected volume. Also let Q be the new volume corrected for temperature but not for pressure.

Then by (83.) $Q = V' \cdot \frac{1 + kt''}{1 + kt'}$, which corrects temperature only;

and by (77.) $\quad \frac{V''}{Q} = \frac{p'}{p''}$,

or $\quad V'' = Q \cdot \frac{p'}{p''}$, which corrects for pressure,

$$= V' \cdot \frac{p'}{p''} \cdot \frac{1 + kt''}{1 + kt'} \text{ by substitution.}$$

Example. Having 100 cubic inches of gas at 50° Fahrenheit and Barometer 29 inches; required the volume of this at 60° Fahrenheit and Barometer 30 inches.

Generally (88.) $V'' = V' \cdot \frac{p'}{p''} \cdot \frac{1 + kt''}{1 + kt'}$.

Here $V' = 100 \quad p' = 29 \quad p'' = 30 \quad t' = 50 - 32 = 18 \quad t'' = 28$;

$$\therefore V'' = 100 \cdot \frac{29}{30} \cdot \frac{508}{498} = 98.6 \text{ cubic inches.}$$

(89.) Similarly. Having the weight, pressure, and temperature of a given volume of gas: required the weight of an equal volume when pressure and temperature both vary.

The same for weight.

The same notation remaining, let Q represent the new weight produced, supposing the temperature alone had varied.

Then by (87.) $\quad Q = W' \cdot \frac{1 + kt'}{1 + kt''}$.

But weight $\propto$ density $\propto$ pressure,

$$\therefore \frac{W''}{Q} = \frac{p''}{p'}, \text{ and } W'' = Q \cdot \frac{p''}{p'},$$

and by substituting the value of Q before obtained

$$W'' = W' \cdot \frac{p''}{p'} \cdot \frac{1 + kt'}{1 + kt''}.$$

Example. If 100 cubic inches of gas, Thermometer 50° Fahrenheit, Barometer 29 inches, weigh 50 grains; what will 100 cubic inches weigh, Thermometer 60° Fahrenheit, Barometer 30 inches?

Generally, $\quad W'' = W' \cdot \frac{p''}{p'} \cdot \frac{1 + kt'}{1 + kt''}$.

Here $W' = 50 \quad p' = 29 \quad p'' = 30 \quad t' = 50 - 32 = 18$ and $t'' = 28$;

$$\therefore W'' = 50 \cdot \frac{30}{29} \cdot \frac{498}{508} = 50.706 \text{ grains.}$$

(90.) All that has hitherto been said respecting the properties of a pure and dry gas applies equally to atmospheric air, or to a mixture of gases, provided

True for all dry gases.

only that no moisture be present, since it is proved by the experiments of Gay Lussac that all gases undergo the same dilatations by the same increments of temperature. And that the actual *cubic dilatation* of gas, in being heated from 32° Fahrenheit to 212° Fahrenheit, is .375 of the original volume: so that (Heat, 52.) the cubic dilatation due to one degree

$$\left.\begin{array}{l} \text{of Fahrenheit} = \dfrac{1}{480} = 0.002083 \\ \text{of Centigrade} = \dfrac{1}{266.66} = 0.00375 \\ \text{of Reaumur} = \dfrac{1}{213.33} = 0.0046875 \end{array}\right\} \text{of the volume at melting ice.}$$

Moist Gases.

Effect of moisture.

(91.) The general principles which regulate the effects of moisture when present in gases have been already noticed in the *Treatise on* Heat, (79.) *et seq.*, we would offer, therefore, in as concise a form as possible, the practical results which demand the Chemist's remembrance and attention.

Let V_d be the volume of a dry gas and V_m the volume to which the former increases upon being saturated with moisture.

Let $p =$ the atmospheric pressure, or the tension of the dry gas.

Let $f =$ the tension of the vapour due to the temperature and to be found from tables.

Then since the elasticity of a gas varies inversely as its volume.

Elasticity of dry gas (p) : elasticity of moist :: $V_m : V_d$,

$$\therefore \text{Elasticity of moist} = p \cdot \frac{V_d}{V_m}.$$

But (Heat, 91.) $p = p \cdot \dfrac{V_d}{V_m} + f.$

Hence $$V_d = \frac{p-f}{p} \cdot V_m,$$

and $$V_m = \frac{p}{p-f} \cdot V_d.$$

Example. Having 100 cubic inches of gas saturated with moisture at Barometer 30 and Thermometer 60° Fahrenheit. Required the volume of this gas when dry.

Here $f = .524$ by Dalton's tables $p = 30$ $V_m = 100$;

$$\therefore V_d = \frac{30 - .524}{30} \cdot 100 = 98.253 \text{ cubic inches.}$$

(92.) And if V_v represent a virtual volume due to the vapour, or, in other words, the quantity by which V_d is increased by the moisture,

$$V_m = V_d + V_v = \frac{p}{f} V_v,$$

and $$V_v = \frac{f}{p} V_m,$$

or, $$= \frac{f}{p-f} \cdot V_d.$$

(93.) Supposing that we had a given volume of a moist gas at some given temperature and pressure, it is easy to reduce this volume to that which is due to the standard temperature and pressure by (88.): but we only speak of such a change as shall not condense the moisture.

Thence having the volume of moist gas we obtain the volume of dry gas therein contained by (91.)

(94.) But suppose that we had obtained the specific gravity of a gas in a state of saturation; and that it was required to calculate the specific gravity of the same gas when dry.

Let $p =$ the barometric pressure.

Let $f =$ the elasticity of the vapour due to the temperature found from Tables, Heat, *Encyclopædia Metropolitana*, Appendix, Table V. and Art. (79.) of the Treatise, and let S_d, S_v, and S_m be the specific gravities of the dry gas, the vapour diffused throughout the volume of gas, and of the moist gas respectively. V_m, V_d, and V_v the volumes respectively.

Then $$V_m S_m a = V_d S_d a + V_v S_v a,$$

where $a =$ the weight of a cubic inch of the gas at the given temperature and pressure; for instance, in the case of atmospheric air at Barometer 30 Thermometer 60° Fahrenheit, $a = .305$ Troy grains,

$$\therefore V_m S_m = \frac{p-f}{p} V_m S_d + V_v S_v;$$

and if we suppose that the specific gravity which we have taken from the Table is the one belonging to a volume of vapour equal to the entire original volume of moist gas,

$$V_v = V_m,$$

so that $$S_m = \frac{p-f}{p} \cdot S_d + S_v,$$

or $$S_d = \frac{p}{p-f} \cdot (S_m - S_v).$$

But if, on the other hand, we conceive that the volume of vapour is to be estimated on the supposition that its volume is reduced to the volume of the dry gas, then V_v becomes $= V_d$,

and we have $$S_m = \frac{p-f}{p} (S_d + S_v),$$

or $$S_d = \frac{p}{p-f} S_m - S_v,$$

which is the view taken by Professor Thomson, in his interesting experiments, *First Principles*, vol. i. p. 66.

(95.) Formula for obtaining f immediately may be seen in the *Treatise on* Heat, (79.)—(82.): or its value may be found from the Table V., Appendix to the same Treatise.

(96.) In these calculations we frequently require the specific gravity of vapours, especially that of the vapour of water at different temperatures. Now, as far as we at present know, the specific gravity of vapour in contact with the fluid from which it is formed varies directly as the elastic force of that vapour. Heat, *Encyclopædia Metropolitana*. (77.)

Hence $$S_n = \frac{f_n}{f_{212}} \times S_{212},$$

where S_n and S_{212} represent the specific gravities at n° Fahrenheit and 212° Fahrenheit respectively, f_n and

f_{32}, the elastic forces due to the temperatures; which may be found from the Table V., HEAT, *Encyclopædia Metropolitana*, Appendix: and S_{212}, from Gay Lussac's experiments, $= .62$;

$$\therefore S_n = \frac{f_n}{30}\, .62.$$

(97.) Should the case occur of gas confined in vessels standing over other liquids, the same formula would serve, varying only the expressions of Art. (79.), which depends upon the specific gravity of the liquid; and of Art. (94.), which depends upon the specific gravity of the vapour of the liquid, at the temperature of any experiment.

Mixed and Moist Gases.

(98.) And it is obvious that calculations on mixed gases are easily made on the principles already laid down; remembering that they differ in specific gravity, but all undergo equal expansions or contractions by equal changes of temperature, or by equal variations of pressure.

On taking the Specific Gravity of Gases.

(99.) Being now competent to introduce the necessary corrections, we may proceed to the practical processes for ascertaining the specific gravity of gases. For this purpose we require a good air-pump; a large flask with a stop-cock; and an air-jar graduated into cubic inches and provided also with a stop-cock.

To obtain then the weight of a known volume of any gas, the flask is to be exhausted, then most accurately weighed, then filled with the gas by screwing it to the stop-cock of the air-jar containing the gas: the weight is to be then again taken, and it is evident that the increase of weight is the weight due to the number of cubic inches that have entered the flask, as shown by the air-jar.

The specific gravity of dry atmospheric air is always made unity, and the weight of one cubic inch of dry atmospheric air is .305 grains Troy at Barometer 30, Thermometer 60° Fahrenheit.

Therefore at any pressure p and any temperature $t°$ Fahrenheit, let V cubic inches of a dry or moist gas weigh W grains; and let a be the weight of a cubic inch of dry atmospheric air at the pressure p and temperature $t°$ Fahrenheit: so that the weight of a volume V of dry common air at p and t would be $= a\,V$, then

$$S \text{ (the specific gravity of the gas dry or moist)} = \frac{W}{a\,V},$$

and from hence, if moist the specific gravity of the same gas when dry may be found from Art. (94.)

(100.) Professor Thomson has proposed and employed a method still more simple for taking the specific gravity of gases, with this advantage, that it is more independent of a very accurate exhaustion of the flask.

Let W, W′, and W″, be the weights of the flask before exhaustion, after exhaustion, and when filled with the gas respectively.

Then $W - W'$ is the weight of the atmospheric air removed from the flask: and $W'' - W'$ is the weight of the gas admitted; and since the volumes are in both cases the same, the specific gravities are as the weights directly.

$$\text{Hence } S \text{ (the specific gravity of the gas)} = \frac{W'' - W'}{W - W'},$$

which gives the specific gravity of the gas dry or moist, as it may happen to be, and is so far independent of the atmospheric pressure and temperature.

Specific Gravity of Vapours.

Specific gravity of vapours.

(101.) By far the best method for ascertaining the specific gravity of vapours is that contrived by M. Gay Lussac, and well described in Biot's *Physique*, vol. i. p. 291. The principle employed is that of ascertaining the relative volumes of a body in the liquid state, and of the same body when converted into vapour at a known temperature. We fear that it would occupy too much space, or the process is well worthy of insertion in this place.

Power of Conducting Heat.

Variable power of conducting heat.

(102.) A heated body, if placed under similar circumstances, will cool with different velocities in different gases. We are of opinion that this can scarcely be said to depend solely upon a difference in the conducting power of these bodies; in some degree this may be the case, but probably the effect produced depends chiefly upon the motion of the gaseous molecules by which currents are produced, and thus the heat is successively carried off rather than truly conducted. These views are favoured by the circumstance that the powers of different gases in favouring the escape of caloric from a heated body, seem to be in some inverse ratio of their density. It was found by Dulong and Petit that the nature of the surface of the heated body did not affect the results; but it has been shown by Count Rumford's experiments, that moisture in all gases materially aids their power to abstract caloric from the heated body.

This subject has engaged the attention of Mr. Dalton and Sir H. Davy; the latter suffered the bulb of a Thermometer, which had been heated to 160° Fahrenheit, to cool in 21 cubic inches of each gas, at temperature 52° Fahrenheit.

The thermometer cooled down to 106° Fahrenheit in the different gases, in the following times:

	m.	sec.
Atmospheric air	2	0
Hydrogen	0	45
Olefiant gas	1	15
Coal gas	0	55
Azote	1	30
Oxygen	1	47
Nitrous oxide	2	30
Carbonic acid	2	45
Chlorine	3	6

Power of producing sound.

(103.) The different gases possess different powers in the propagation of sound; but this subject forms rather a part of the Science of Acoustics. *Vid.* Kirby, Merrick, and Leslie's experiments, in Nich. *Jour.* xxvii. and xxxiii.; *Phil Mag.* xlv.; *Trans. Camb. Phil. Soc.* vol. i.

(104.) It has been already stated (66.) and (72.) that certain Solids and Liquids absorb Gases. On this subject we cannot do better than offer the following excellent statement by Dr. Henry.

Solids.

"All solid bodies, that possess a certain degree of porosity, are capable of absorbing gases.

"This was first observed in charcoal. It has been found also by Saussure, jun. to belong to a stone called meer-schaum, to adhesive slate, asbestos, rock cork, and other minerals; and to raw silk and wool. The following general principles are deducible from the experiments of Saussure. (*h.*)

1. "It is necessary to deprive the solid of the air which it naturally contains. When of a nature not to be injured by heat, this is most effectually done by igniting the solid, and quenching it under mercury, where it is to be kept, till admitted to a given volume of the gas to be absorbed. Solids that are decomposable by heat, may be deprived, though less effectually, of air, by placing them under a receiver, which must then be exhausted by the air-pump.

2. "The same solid absorbs different quantities of different gases. Charcoal, for instance, condenses 90 times its bulk of ammoniacal gas, and not twice its bulk of hydrogen.

3. "Solids, chemically the same, absorb different quantities of the same gas, according to their state of mechanical aggregation. Thus the dense charcoal of box-wood absorbed 7½ volumes of air, while a light charcoal, prepared from cork, did not absorb a sensible quantity.

4. "Different solids absorb different quantities of the same gas; the quantity of carbonic acid absorbed by charcoal being about seven times greater than that absorbed by meer-schaum.

5. "When the solid exerts no chemical action on the gas, the absorption is terminated in 24 or 36 hours.

6. "The effect of moistening the solid is to retard the absorption, and to diminish its amount; and when a gas has actually been absorbed, it is again driven out unchanged, partly by water of the ordinary temperature, and entirely by exposure to a boiling heat.

7. "During the absorption of a gas by a solid, the temperature of the latter rises several degrees, and bears a proportion to the absorbability of the gas, and the rapidity with which it is condensed.

8. "Solids condense a greater number of volumes of the more absorbable gases, under a rare than under a dense atmosphere; but if the absorption be reckoned by weight, it is most considerable under the latter state.

9. "When a solid, saturated with any one gas, is introduced into an atmosphere of any other gas, a portion of the first is expelled, and a part of the second takes its place.

"Gases are absorbed by liquids."

On this subject the following general principles may be laid down.

Liquids.

1. "The same liquid absorbs different quantities of different gases. Thus water takes up its own bulk of carbonic acid, and not one-fiftieth of its bulk of hydrogen gas.

2. "Different liquids absorb different quantities of the same gas. Alcohol, for instance, absorbs almost twice as much carbonic acid as is taken up by an equal volume of water.

3. "The absorption is promoted by first freeing the liquid from air, either by long-continued boiling in a vessel with a narrow neck, or by the air-pump. It requires also brisk and long-continued agitation, especially with the less absorbable gases.

4. "It does not appear that the gases are absorbed by all liquids in the same order. For example, of four gases, naphtha absorbs most olefiant gas; oil of lavender most nitrous oxide; olive oil most carbonic acid; and solution of muriate of potash most carbonic oxide.

5. "The viscidity of liquids, though it does not much influence the amount absorbed, occasions a longer time to be spent in effecting the absorption. On the other hand, the amount of any gas which is absorbed by water, is diminished by first dissolving in the water any saline substance.

6. "In general the lightest liquids possess the greatest power of absorbing gases; whereas, when there is no evident Chemical action, the heaviest gases are absorbed most copiously, and rapidly, by the same liquid.

7. "The temperature of a liquid is raised by the absorption of a gas, in proportion to the amount and the rapidity of the absorption.

8. "In all liquids the quantity of gases absorbed are directly as the pressure. For example, a liquid which absorbs its own bulk of gas under the pressure of the atmosphere, will still absorb its own bulk of the same gas under double, triple, &c. pressure; but its own bulk of gas, twice compressed, is equal to double its bulk of gas ordinarily compressed, and so on. The proofs of this law I have given at length in the *Philosophical Transactions* for 1803.

9. "When water, or, probably, any other liquid, is agitated with a limited quantity of any mixture of two gases, it does not absorb one gas to the exclusion of the other, but absorbs a portion of both. In this case, the density of each gas, in the water or liquid, has a constant relation to that without, *for the same gas.* Thus in carbonic acid gas, the density is the same within and without the water; in olefiant gas and phosphuretted hydrogen, the density within is 1-27th of that without; in azote and hydrogen, it is about 1-50th, according to Dalton, though he originally stated it to be 1-64th, under the impression that the distances of the particles within were always some multiple of those without. This concise enunciation of the general law, deduced by Mr. Dalton from his experimental inquiries, will be better understood by the illustrations contained in a Paper published in the *Annals of Philosophy*, vol. vii. p. 216, where the reader will find a formula for ascertaining the quantities of mixed gases absorbed by water.

"The principle on which gases are absorbed and retained by liquids is still a subject of controversy. By Berthollet, Thomson, Saussure, and the generality of Chemists, it is ascribed, in all cases, to the exertion of a Chemical affinity between the gas and the liquid; but it is contended by Mr. Dalton and myself, that the effect in most cases is chiefly, if not wholly, mechanical. The discussion would lead me into details of too great a length; and I refer, therefore, for a statement of the argument, to two Papers which I have published in the eighth and ninth volume of Nicholson's *Journal*; to Mr. Dalton's *New System of Chemical Philosophy*; and to his Essay in the seventh volume of Dr. Thomson's *Annals*, which contains a reply to the objections advanced against the mechanical theory by Saussure, in the sixth volume of the same work. This reply seems to have unaccountably escaped the notice of several writers, who continue to urge the objections of Saussure, after they have been fully and satisfactorily answered by Mr. Dalton." (*i.*)

05.) It is obvious that no Chemical classification rise out of the state of aggregation in which bodies ; this state being entirely dependent upon Pressure Temperature. In the usual condition of things at urface of this Earth we are at present acquainted four simple Gases, and about seventeen compound Most of the liquid substances which bear the of proximate elements, are combinations of those ents with water, but with some, such as the oils, presence of water is incompatible. There are forty-six ultimate elements in the solid state, a much more considerable number of proximate formed by the combinations of these with each or with the Gases. The simple elementary ances amount at present to fifty-three, as enuted in Art. (4.)

General Chemical Properties.

06.) We now advance towards those properties are more strictly Chemical—the primary object s Treatise.

on these properties numerous classifications have founded, and although in part abandoned at the nt time in favour of other terms more rigidly ical, yet we so frequently use the words Airs, s, Metals, Alkalis, Acids, &c., that it will be proper y to enumerate the leading characteristics of these s of substances.

e word Air is sometimes employed to designate e permanently elastic fluids, and in this sense it is ymous with the word Gas ; but it is more com- restricted to the atmospheric air, a mixture pally of two Gases, in which we live and breathe. Physical properties of the Gases have been already ted to, and their Chemical ones will form a part r future researches, as upon these their distinctive cteristics depend.

e term Earths is still applied to one class of subes, though rather loosely, for it has been found n all general Chemical properties the Earths and Metallic oxides are identical; in fact, the Earths ll oxides, and nearly all of them have Metallic . As an illustration of the characteristics of this of bodies we give the following definition from a but early Chemical author, who says, "Earths nsipid ; soluble, but in very small proportion, in water or oil ; not inflammable, not ductile; not e *per se.*" By insipid we are to understand not nor alkaline. And the powers of the Voltaic pile he Gas blowpipe have shown that they are fusible . When in the language of modern Chemistry ord Earth occurs, we must understand by it some f the following oxides:—Silica, Zirconia, Yttria, ua, Thorina, Alumina, Magnesia, Lime, Strontia, ryta. Where the Alkaline Earths are spoken of, o the three last enumerated that the term applies.

e Metals are distinctively recognised to be such by Physical properties, and not by their Chemical Of these the two that are considered essential, at they conduct Electricity, and that they possess degree of lustre. They are all capable of comg with Oxygen, though with very different degrees cility. The Metals at present known amount to

bstances of another sort are called the Alkalis, l marked though not a numerous class of Bodies. The term Alkali is derived from the Arabic name of the plant (*Salsola Kali*), from which one of these substances has long been extracted. The general properties of the Alkalis, especially as developed in the stronger ones, are as follows:—They change blue vegetable colours to green; and if such colours have been changed to purple or to a more vivid red by acids, they destroy that sort of action, and when used in sufficient quantity turn them absolutely to green. The same powers they possess even when saturated with Carbonic Acid—a property which the Alkaline Earths are without. Their taste is acrid, possibly in great degree arising from their power of dissolving all animal matter with an energy proportionate to their state of concentration. They readily combine with oils or fatty matters, so as to form soaps. Their carbonates are soluble in water, but the carbonates of the Alkaline Earths are not so. Three of the Alkalis consist of Metallic Bases, united with Oxygen: *viz.* Potassa, Soda, and Lithia. One, *viz.* Ammonia, consists of two Gases, Hydrogen and Nitrogen; and the vegetable Alkalis, which are rather numerous, consist of various combinations of Oxygen, Hydrogen, and Carbon.

Acids.

The term Acid is in familiar use, and is generally understood by all: its Chemical sense accords with, or is in fact adopted from ordinary language. Acids are substances having a sour taste; they are frequently highly corrosive of animal and vegetable bodies, and they change purple vegetable colours to a brighter red. Their most distinctive Chemical property is that they unite with other substances called bases, such as the Alkalis, the Earths, and Metallic oxides, and form a new class of bodies called Salts, in which the antagonist properties of both Acid and base undergo great modifications, or are absolutely annihilated.

We are in the habit of saying that one Acid is stronger than another, but the measure of the strength of the Acids respectively is not without some uncertainty. Various propositions have been made as to the scale to be adopted for this purpose, but none of these are quite free from objections. That which is most employed was proposed by Berthollet, and is taken from the relative quantities of different Acids required to saturate a given quantity of some base, but the plan is not free from objections.

The theory of Acidification, that is the effective cause producing acid properties, has engaged the attention of several Chemists; but as at this time there cannot be said to be any prevailing belief on the subject, we content ourselves with pointing out, by a reference, where the student may find any information that he may require on this subject. (*k*.)

(107.) The Etymology of the word Oxygen perpetuates the memory of a belief that once existed of that substance forming the element essential to the developement of acid properties. This was, however, an error, as it will be seen from the following lists that the presence of Oxygen is not necessary to the formation of an Acid; and also that Hydrogen, which is in many cases the antagonist of Oxygen, is capable of becoming the acidifying principle: while in some Acids neither the one nor the other exists.

Class 1. Acids with Oxygen, and a nonmetallic radical:

1. Chloric. 2. Oxiodic. 3. Bromic. 4. Carbonic. 5. Boracic. 6. Phosphorous. 7. Phosphoric. 8. Hyposulphurous. 9. Sulphurous. 10. Hyposulphuric.

11. Sulphuric. 12. Selenic. 13. Nitrous. 14. Nitric. 15. Cyanic?

Class 2. Acids with Oxygen and a metallic radical.

1. Arsenious. 2. Arsenic. 3. Molybdous. 4. Molybdic. 5. Chromic. 6. Tungstic. 7. Columbic. 8. Antimonious. 9. Antimonic. 10. Titanic.

Class 3. Acids without Oxygen, but with Hydrogen.

1. Hydro-chloric. 2. Hydro-fluoric. 3. Hydriodic. 4. Hydro-bromic. 5. Hydro-sulphuric. 6. Hydroselenic, with one or two others of more doubtful constitution.

Class 4. Acids without Oxygen or Hydrogen.

1. Boro-fluoric. 2. Silico-fluoric. 3. Chloriodic.

Class 5. Organic Acids of animal and vegetable origin. Of these there are about sixty, which we shall have occasion to enumerate hereafter.

From divisions like these no Chemical classification can well arise; though it is convenient that they be remembered, for the sake of obtaining general views of groups of substances having numerous properties in common.

Organic and Inorganic bodies.

(108.) There are also of another sort, two well-marked classes into which all substances are frequently divided. These are Inorganic and Organic. By the former we understand all such substances, whether simple or compound, as seem not to be capable of forming the chief constituents of bodies endowed with the functions of animal or vegetable life; although in such bodies they frequently exist as ultimate elements. In this division are comprehended the Metals, Earths, fixed Alkalis, the stronger Acids, and what were formerly called the simple non-metallic elements.

On the other hand, that which is called the Chemistry of Organic bodies, induces an examination of the various substances which form the existent elements, or the educts and products of animal and vegetable Organization. This branch of our Science chiefly refers to proximate elements, of which the number is very considerable. The properties of these bodies are well and distinctively marked; though in numerous cases the ultimate elements into which they may be resolved are precisely the same. Thus the Vegetable Acids and Alkalis may all be resolved into Oxygen, Hydrogen, and Carbon; and it is the various proportions in which these elements exist in the different substances which form the sole distinction discoverable upon their ultimate analysis.

Nomenclature.

(109.) We now proceed to the nomenclature of Chemical Compounds, and to the laws which regulate them, *viz.* the doctrines of *Affinity*, *Definite Proportion*, and the *Theory of Atoms*. After a careful examination of the systematic Treatises of our own and other Countries, and even after having prepared the greater part of what we deemed it advisable to insert upon the subject, we have not hesitated to reject it, in favour of the Essay of a contemporary writer. In the main, we consider Dr. Turner's analysis of this part of our subject as the most clear that can be presented in the present state of our knowledge. We, therefore, shall make a considerable abstract from his *Elements of Chemistry*, taking only the liberty of making some slight alterations or additions which appear to us, or which have been pointed out by his reviewers, to be necessary. In some degree we shall also have to bring forward and discuss Professor Thomson's additions to our nomenclature, as developed and employed in his valuable Work on the *First or Fundamental Principles of Chemistry*.

(110.) "Chemistry is indebted for its nomenclature to the labours of four celebrated Chemists, Lavoisier, Berthollet, Guyton Morveau, and Fourcroy. The principles which guided them in its construction are exceedingly simple and ingenious. The known elementary substances, and the more familiar compound ones, were allowed to retain the appellations which general usage had assigned to them. The newly discovered elements were named from some striking property. Thus, as it was supposed that acidity was always owing to the presence of the vital air discovered by Priestley and Scheele, they gave it the name of Oxygen, derived from two Greek words signifying generator of Acid; and they called inflammable air Hydrogen, from the circumstance of its entering into the composition of water."

"Compounds in which Oxygen forms a part were called Acids or Oxides, according as they do or do not possess acidity. An oxide of iron or copper signifies a combination of those metals with Oxygen, which has no acid properties. The name of an Acid was derived from the substance acidified by the Oxygen, to which was added the termination *ic*. Thus Sulphuric and Carbon*ic* Acids signify acid compounds of Sulphur and Carbon with Oxygen Gas. If sulphur or any other body should form two Acids, that which contains the least quantity of Oxygen is made to terminate in *ous*, as Sulphur*ous* Acid. The termination *uret* was intended to denote combinations of the simple non-metallic substances either with one another, with a metal, or with a metallic oxide." This plan is still adhered to in France in the words Chloruret, Ioduret, &c. but in our own Country the analogy of the word oxide has been followed in the case of the five electro-negative bodies; thus we say chloride, iodide, fluoride, &c. "Sulph*uret* and carb*uret* of iron, for example, signify compounds of sulphur or carbon with iron. The different oxides or sulphurets of the same substance were distinguished from one another by some epithet, which was commonly derived from the colour of the compound, such as the black and red oxides of iron, the black and red sulphurets of mercury. Though this practice is still continued occasionally, it is now more customary to distinguish degrees of oxidation by the use of derivatives from the Greek. *Prot*oxide signifies the first degree of oxidation, *Deut*oxide the second, *Trit*oxide the third, and *Per*oxide the highest." The last term is rather objectionable, as being a departure from the Greek system of derivation, and as it is liable to be changed from new discoveries in the extent of oxidation. "The sulphurets, carburets, &c. of the same substance are designated in a similar way. The combination of Acids with Alkalis, Earths, or Metallic oxides, were termed Salts, the names of which were so contrived as to indicate the substances contained in them. If the acidified substance contains a maximum of oxygen, the name of the Salt terminates in *ate*; if a minimum, the termination in *ite* is employed. Thus the sulph*ate*, phosph*ate*, and arseni*ate* of potash, are Salts of sulphuric, phosphoric, and arsenic Acids; while the terms sulph*ite*, phosph*ite*, and arsen*ite* of potash denote combinations of that Alkali with the sulphurous, phosphorous, and arsenious Acids." This method, however, is found insufficient for its purpose, as it only provides for two degrees of oxigenation; hence the intermediate terms of *hypo* and *hyper* have been subsequently introduced.

"The advantage of a nomenclature which disposes ferent parts of a Science in so systematic an order, ;ives such powerful assistance to the memory, is ılable. The principle has been acknowledged in ıntries where Chemical Science is cultivated, and inutest details of it have been adopted in Britain. ıst be admitted, indeed, that some parts of it are ive. The erroneous idea of oxygen being the ıl acidifying principle has exercised an injurious ace over the whole structure. It would have been nient also to have had a different name for hydro- but it is now too late to attempt a change, for the ion attending such an innovation would more counterbalance its advantages. The original no- lature has therefore been preserved, and such addi- made to it as the progress of the Science rendered ary. The most essential improvement has been sted by the discovery of the laws of Chemical nation. The different Salts formed of the same tuents were formerly divided into *neutral*, *super*, *ıbsalts*. They were called neutral, if the Acid and are in the proportion for neutralizing one another; ıalts, if the Acid prevails; and subsalts, if the is in excess. The name is now regulated by the constitution of the Salt. If it be a compound atom of the Acid to one atom of the Alkali, the c name of the Salt is employed without any other on; but if two or more atoms of the Acid be attached to one of the base, or two or more atoms of the base to one of the Acid, a numeral is prefixed so as to indicate its composition. The two Salts of sulphuric Acid and potash are called sulphate and bisulphate; the first containing one atom of the Acid to one atom of the Alkali; and the latter two of the former to one of the latter. The three Salts of oxalic Acid and potash are termed the *ox*alate, *bin*oalate, and *quadr*-oxalate of potash; because one atom of the Alkali is united with one atom of Acid in the first, with two in the second, and with four in the third Salt. As the numerals which denote the atoms of the Acid in a super-salt are derived from the Latin language, Dr. Thomson proposes to employ the Greek numerals, *dis*, *tris*, *tetrakis*, *&c.* to signify the atoms of Alkali in a subsalt.*

"This method is in the true spirit of the original framers of our nomenclature. Chemists have already begun to apply the same principle to other compounds besides Salts; and there can be no doubt that it will be applied universally whenever our knowledge shall be in a state to admit of it." (*l.*)

(111.) The following paradigma will, perhaps, render the system of nomenclature more intelligible to the Chemical student.

For the sake of brevity, S. M. is put for sulphate of mercury.

&c. = Tetarto-tri S. M. = Tetarto-di S. M. = Tetarto- S. C. = Tetarto-bi S. M. = Tetarto-ter S. M. = &c.

ito-tetraki S. M. = Trito-tri S. M. = Trito-di S. M. = Trito- S. M. = Trito-bi S. M. = Trito-ter S. M. = Trito-quater S. M.

etraki S. M. = Deuto-tri S. M. = Deuto-di S. M. = Deuto- S. M. = Deuto-bi S. M. = Deuto-ter S. M. = Deuto-quater S. M.

-tetraki S. M. = Proto-tri S. M. = Proto-di S. M. = Proto- S. M. = Proto-bi S. M. = Proto-ter S. M. = Proto-quater S. M.

Sub-tetraki S. M. = Sub-tri S. M. = Sub-di S. M. = Sub- S. M. = Sub-bi S. M. = Sub-ter S. M. = Sub-quater S. M.

Sub-oxide of M. = Protoxide of M. = Deutoxide of M. = Tritoxide of M. = Tetartoxide of M. = &c.

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* preceding scheme is only the rigid develope- of a plan proposed by Professor Thomson, in the Introduction to his *First Principles*, published in 1825.

The degrees of oxidation are marked by prefixes derived from the Greek, which, to be consistent, run Proto-, Deuto-, Trito-, Tetarto-, &c. First, Second, Third, Fourth, &c. The only deviation from this plan occurs in the word Sub, which should have been drawn *Græco Fonte*, but being already in use, any alteration might prove inconvenient.

Upon each degree of oxidation a series of saline combinations may be produced; and it is necessary that words should be found to express atoms of Acid or of base *so many times taken*. Where the atom of base remains unity, and the atom of acid is once, twice, thrice, four times, &c. taken into combination, an ascending series of Latin numerals is employed. These obviously must be *Bis*, *Ter*, *Quater*, &c. And where, on the contrary, the atom of acid remains unity, and the atoms of base multiply, a series of numerals derived from the Greek are employed upon Dr. Thomson's plan. These, of course, must be from the words δὶς, τρὶς, τετράκις, &c. as in the paradigma.

The first part, therefore, of the name of a Salt so compounded informs us in what state of oxidation the metal exists; the second part gives us the proportion between the number of atoms of Acid and of base. If this second part be of Latin derivation, we know that our compound is a *Supersalt;* if of Greek derivation, we learn that it is a *Subsalt.*

For example, *Deuto-ter-sulphate of mercury* represents a Salt having for its base the oxide composed of 2 atoms of oxygen + 1 atom of mercury; and containing 3 atoms of Acid + 1 atom of base. But by *Deuto-tri-sulphate* of mercury we should understand the same base and the same Acid united in the proportion of 1 atom of Acid + 3 atoms of base.

In compounds of 1 atom of Acid + 1 atom of base we frequently leave out the prefix Prot-, in common usage, without inconvenience; but in those cases where numerous combinations exist, it is necessary always to make use of it; otherwise cases like this might occur, *viz.* a confusion between *Trito-sulphate* of mercury and *Tri-sulphate* of mercury; which only become sufficiently distinct by adhering to the canon of nomenclature that gives *Trito-sulphate* of mercury and *Proto-tri-sulphate* of mercury.

The definite proportions of all combinations between simple substances are expressed by Prot-, Deut-, Trit-, &c. as in the case of the oxides. Thus we say Proto-chloride, Deut-iodide, Trito-sulphuret, &c.

Some regard must be had to euphony, and the ordinary usages of compound words in constructing such names; thus we say *Proto-bin-acetate*, and not *Proto-bi-acetate; Deuto-trit-oxalate*, and not *Deuto-tri-oxalate.*

(112.) There are, however, several metallic oxides which the above system does not enable us clearly to express. Such are those which we at present describe in terms of half atoms, saying that there are 1½ atoms of oxygen + 1 atom of base. It is probable that future researches will dispel this apparent anomaly, but for the present we are under the necessity of speaking of such combinations, and it would be convenient if our nomenclature could truly represent them to the mind. At present the oxide of lead containing 1 atom of oxygen + 1 atom of base is called the *Protoxide;* that containing 1.5 atom of oxygen + 1 atom of base is called the *Deutoxide;* and that containing 2 atoms of oxygen + 1 atom of base is called the *Tritoxide.* But upon the common principles of our nomenclature, we should understand by these three words, three different oxides, containing 1, 2, and 3 atoms of oxygen respectively. It is with great diffidence, and with a full sense of the evils arising from any change made upon established names, that we venture to propose a plan for obviating this inconvenience. To obtain our end, we must borrow a custom from the German languag[illegible] Ask a German what o'clock it is, and he will answ[illegible] you *halb sieben*, for half-past six; and as we must ke[illegible] to the Greek language for expressing the degrees [illegible] oxidation, we might use the prefix *hemi*, (ἡμισυ, a ha[illegible] Thus we should have in the case of Lead

1 Oxygen + 1 Metal = Protoxide of Lead.
1½ ditto + 1 ditto = Hemi-deutoxide of L[illegible]
2 ditto + 1 ditto = Deutoxide of Lead.

In the case of Manganese

1 Oxygen + 2 Metal = Sub-oxide.
1 ditto + 1 ditto = Protoxide.
1½ ditto + 1 ditto = Hemideutoxide.
2 ditto + 1 ditto = Deutoxide.
3 ditto + 1 ditto = Tritoxide.

In this manner we could express any known combination, so that the name should fully express the relative atomic proportions of its constituents. We would also adopt the practice of many Chemists in banishing for ever the prefix *Per*, which has been used to express the highest degree of oxidation, partly because it is a Latin word, and therefore should not occur in the Greek ascending series: and partly, because we are never certain that we have arrived at the extreme degree of oxidation; and are, therefore, liable to have many of our names of Salts overturned by the discovery of a new degree of oxidation beyond the one with which we were previously acquainted.

At first sight this system of nomenclature may appear to present a formidable array of inharmonious words, but it is to be remembered that only a small proportion of the compounds so described are at present known to exist; and the advantages are not inconsiderable in a system which provides for the discovery of new substances, without requiring any change in names that may previously exist; and which always serves as a scheme of *memoria technica* for the atomic constitutions of the bodies named. We must admit that the plan now proposed may be liable to this objection, that in the strict meaning of the words, Protoxide, Deutoxide, &c., the first, second, &c., oxides are expressed; so that if what we call a Hemideutoxide exists, the Deutoxide is not the second but the third oxide. To us it seems that the choice lies between various methods, which all have their imperfections; but that the advantage of that system which, together with the name of the oxide or Salt, gives us its atomic constitution, outweighs all other considerations. It is also a serious affair to change terms which usage has established, but the plan proposed can scarcely be said to do so.

Affinity.

(113.) "All Chemical phenomena are owing to Affinity or Chemical attraction. It is the basis on which the Science of Chemistry is founded. It is the ruling power with reference to which all the operations of the

ist are conducted, and hence it forms the first and
g object of his study.

ffinity is exerted between the minutest particles of
nt kinds of Matter, causing them to combine so as
n new bodies, endowed with new properties. It
nly at insensible distances ; in other words, appa-
ntact, or the closest proximity, is necessary to its
. Every thing which prevents such contiguity is
stacle to combination, and any force which in-
s the distance between particles already com-
tends to separate them permanently from each
In the first case they do not come within the
of their mutual attraction ; in the second they are
ed out of it. It follows, therefore, that though
y is regarded as a specific power, distinct from the
forces which act on matter, its action may be pro-
, modified, or counteracted, by several circum-
s ; and, consequently, in studying the phenomena
ced by Affinity, it is necessary to begin by inquir-
to the conditions that influence its operation.

he most simple instance of the exercise of Chemical
tion is afforded by the mixture of two substances
ne another. Water and sulphuric acid, or water
cohol, combine readily. On the contrary, water
little disposition to unite with sulphuric ether,
till less with oil ; for, however intimately their
les may be mixed together, they are no sooner left
t, than the ether separates almost entirely from
ter, and a total separation takes place between
uid and the oil. Sugar dissolves very sparingly
ohol, but to any extent in water ; while camphor
olved in very small quantity by water, but abun-
by alcohol. It appears from these examples,
hemical attraction is exerted between different
with different degrees of force. There is some-
no proof of its existence at all ; between some
nces it acts very feebly, and between others with
energy.

imple combination of two principles is a common
ence. The solution of Salts in water, the combus-
f phosphorus in oxygen gas, and the neutraliza-
f a pure Alkali by an Acid, are instances of the
The phenomena are, however, often more com-
It frequently happens that the formation of a new
und is attended by the destruction of an existing
The only condition necessary for this effect is the
ce of some third body, which has a greater Affi-
r one of the elements of a compound, than they
or one another. Thus oil has an affinity for the
e Alkali ammonia, and will unite with it, forming
y substance called a liniment. But the ammonia
still greater attraction for sulphuric Acid ; and
, if the Acid be added to the liniment, the Alkali
uit the oil, and unite by preference with the Acid.
solution of camphor in alcohol be poured into
, the camphor will be set free, because the alcohol
ines with the water. Sulphuric Acid, in like man-
eparates baryta from Muriatic Acid. Combination
ecomposition occur in each of these cases ; combi-
of the Sulphuric Acid with the ammonia, of the
with the alcohol, and of the baryta with the sul-
Acid ; decomposition of the compounds formed
oil and ammonia, of the alcohol and camphor, and
Muriatic Acid and baryta. These are examples
at Bergmann calls single elective Affinity ; elective,
se a substance manifests, as it were, a choice for
f two others, uniting with it by preference, and to the exclusion of the other. Many of the decompositions that occur in Chemistry, are instances of single elective Affinity.

"The order in which these decompositions take place has been expressed in Tables ; of which the following, drawn up by Geoffroy, is an example :

Sulphuric Acid.

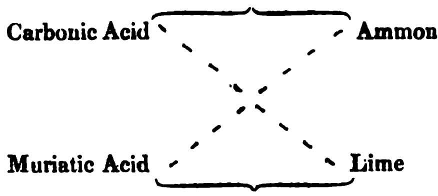
Baryta.
Strontia.
Potash.
Soda.
Lime.
Ammonia.
Magnesia.

"This Table signifies, first, that Sulphuric Acid has an Affinity for the substances placed below the horizontal line, and can, therefore, unite separately with each of them ; and, secondly, that the base of the Salts so formed will be separated from the Acid by adding any of the Alkalis or Earths which stand above it in the column. Thus ammonia will separate magnesia, lime ammonia, and potash lime ; but none of them can withdraw baryta from Sulphuric Acid, nor can ammonia or magnesia decompose the sulphate of lime, though strontia or baryta will do it. Bergmann conceived that these decompositions were solely determined by Chemical attraction, and that, consequently, the order of decomposition represented the comparative forces of Affinity : and this view, from the simple and natural explanation it afforded of the phenomenon, was for a time very generally adopted. But Bergmann was in error. It does not necessarily follow, because lime can separate ammonia from Sulphuric Acid, that the lime has a greater attraction for the Acid than the volatile Alkali. Other causes are in operation which modify the action of Affinity to such a degree, that it is impossible to discover how much of the effect is owing to that power. It is conceivable that the ammonia may in reality have a stronger attraction for Sulphuric Acid than lime, and yet the lime, from the great influence of disturbing causes, might succeed in decomposing sulphate of ammonia.

"The justice of the foregoing remark will be made obvious by the following example : when a stream of hydrogen Gas is passed over the oxide of iron heated to redness, it deprives the iron of its oxygen entirely, combining with it so as to form water. On the contrary, when watery vapour is brought into contact with red hot metallic iron, the oxygen of the water quits the hydrogen, and combines with the iron. It follows from the result of the first experiment, according to Bergmann, that hydrogen has a stronger attraction for oxygen than iron has ; and from the second, that iron has a greater Affinity for oxygen than hydrogen has. But these inferences are incompatible with each other. The Affinity of hydrogen for oxygen must either be equal to that of iron, or greater or less. If the first is the case, then the result of both experiments was determined by modifying circumstances ; since neither of these substances ought on this supposition to take oxygen from the other. If the second, then the decomposition in one of the experiments must have been determined by extraneous causes in direct opposition to the tendency of Affinity.

"To Berthollet is due the honour of pointing out the fallacy of Bergmann's opinion. He was the first to show that the relative forces of Chemical attraction cannot always be determined by observing the order in which substances separate each other when in combination, and that the Tables of Geoffroy are merely tables of decomposition, not of Affinity. He likewise traced all the various circumstances that modify the action of Affinity, and gave a consistent explanation of the mode in which they operate. Berthollet went even a step further. He denied the existence of elective Affinity as an invariable force, capable of effecting the perfect separation of one body from another; he maintained that all the instances of complete decomposition, attributed to elective Affinity, are in reality determined by one or more of the collateral circumstances that influence its operation. But here this acute Philosopher has surely gone too far. Bergmann is admitted to have erred in supposing that the result of Chemical action is in every case owing to elective Affinity; but Berthollet certainly ran into the opposite extreme, in declaring that the effects formerly ascribed to that power, are never produced by it. That Chemical attraction is exerted between bodies with different degrees of energy is indisputable. Water has a much greater Affinity for Muriatic Acid and ammoniacal Gases than for Carbonic Acid and sulphuretted hydrogen, and for these than for oxygen and hydrogen. The attraction of lead for oxygen is greater than that of silver for the same substance. The disposition of gold and silver to combine with mercury, is greater than the attraction of platinum and iron for that fluid. As these differences cannot be accounted for by the operation of any modifying causes, we must admit a difference in the force of Affinity in producing combination. It is equally clear that in some instances the separation of bodies from one another can only be explained on the same principle. No one, I conceive, will contend that the decomposition of Hydriodic Acid by chlorine, or of sulphuretted hydrogen by iodine, is determined by the concurrence of any modifying circumstances.

"Affinity is the cause of still more complicated changes than these which have been just considered. In a case of single elective Affinity, three substances only are present, and two Affinities are in play. But it frequently happens that two compounds are mixed together, and four different Affinities brought into action. The changes that may or do occur under these circumstances are most conveniently studied by aid of a diagram, a method that was, I believe, first employed by Dr. Black, and has since been generally practised. Thus in mixing together a solution of the carbonate of ammonia and muriate of lime, their mutual action may be represented in the following manner:



"Each of the Acids has an attraction for both the bases, and hence it is possible either that the two Salts should continue as they are, or that an interchange of principles should ensue, giving rise to two new compounds, the carbonate of lime, and muriate of ammonia. According to the views of Bergmann, the result is solely dependent on the comparative strength of Affinities. If the Affinity of the Carbonic Acid for the ammonia, and of the Muriatic Acid for the lime, exceed that of the Carbonic Acid for lime, added to that of the Muriatic Acid for ammonia, then will the two Salts experience no change whatever; but if the latter Affinities preponderate, then, as does actually happen in the present example, both the original Salts will be decomposed, and two new ones generated. Two decompositions and two combinations take place, being an instance of what is called double elective Affinity. Mr. Kirwan applied the terms quiescent and divellent, to denote the tendency of the opposing Affinities, the action of the former being to prevent a change, that of the latter to produce it.

"The doctrine of double elective Affinity was assailed by Berthollet on the same ground, and with the same success as in the case of single elective attraction. He succeeded in proving that the effect cannot always be ascribed to the sole influence of Affinity. For, to take the example already adduced, if the carbonate of ammonia decompose the muriate of lime by the mere force of a superior attraction, it is manifest that the carbonate of lime ought never to decompose the muriate of ammonia. But if these two Salts are mixed in a dry state, and exposed to heat, double decomposition does take place, carbonate of ammonia and muriate of lime being formed; and, therefore, if the change in the first example was produced by Chemical attraction alone, that in the second must have occurred in direct opposition to that power. It does not follow, however, because the result is sometimes determined by modifying conditions, that it must always be so. I apprehend that the decomposition of the solid cyanuret of mercury by sulphuretted hydrogen Gas, which takes place even at a low temperature, cannot be ascribed to any other cause than a preponderance of the divellent over the quiescent Affinities."

On the Changes that accompany Chemical Action.

"The leading circumstance that characterises Chemical action is the loss of properties, experienced by the combining substances, and the acquisition of new ones by the product of their combination. The change of property is sometimes inconsiderable. In a solution of sugar or salt in water, and in mixtures of water with alcohol or sulphuric Acid, the compound retains so much of the character of its constituents, that there is no difficulty in recognising their presence. But more generally the properties of one or both of the combining bodies disappear entirely. No ingenuity could guess *a priori* that water is a compound body, much less that it is composed of two Gases, oxygen and hydrogen, neither of which, when uncombined, has ever been compressed into a liquid. Hydrogen is one of the most inflammable substances in nature, and yet water cannot be set on fire: oxygen, on the contrary, enables bodies to burn with great brilliancy, and yet water extinguishes combustion. The Alkalis and Earths were regarded as simple till Sir H. Davy proved them to be compounds, and certainly they evince no sign whatever of containing oxygen Gas and a metal. Numerous examples of a similar kind are afforded by the action of Acids and Alkalis on one another. Sulphuric Acid and potash, for example, are highly caustic. The former is intensely sour, reddens the blue colour of vegetables, and has a strong affinity for Alkaline substances; the latter has a pungent taste, converts the blue colour of vegetables to green, and combines readily with Acids. On adding

principles cautiously to one another a compound
s, called a neutral Salt, which does not in any way
the colouring matter of plants, and in which the
distinguishing features of the Acid and Alkali can
ıger be perceived. They appear to have destroyed
roperties of each other, and are hence said to
ılize one another.

'he other phenomena that accompany Chemical
. are changes of Density, Temperature, Form, and
r.

. It is observed that two bodies rarely occupy the
space after combination which they did separately.
neral their bulk is diminished, so that the specific
y of the new body is greater than the mean of its
onents. Thus a mixture of 100 measures of water,
ın equal quantity of Sulphuric Acid, does not
y the space of 200 measures, but considerably
A similar contraction frequently attends the com-
on of Solids. Gases often experience a remarkable
nsation when they unite. The elements of olefiant
for example, would expand to four times the bulk
t compound, if they were suddenly to become free,
ssume the Gaseous form. But the rule is not
ıt exception. The reverse happens in some
ic compounds; and there are examples of combina-
etween Gases without any change of bulk.

. A change of temperature generally accompanies
ical action. Caloric is evolved either when there
iminution in the bulk of the combining substances,
ıt a change of form, or when a Gas is condensed
liquid, or when a Liquid becomes solid. The heat
l by mixing Sulphuric Acid with water is an
ce of the former; and the common process of
g lime, during which water loses its liquid form,
mbining with that Earth, is an example of the
l. The rise of temperature in these cases is
ısly referable to a diminution in the capacity of
w compound for caloric; but an intense degree of
sometimes accompanies Chemical action under
nstances in which an explanation founded on a
e of specific caloric is quite inadmissible. At
ıt it is enough to have stated the fact; the theory
gs to a different branch of our Science. The pro-
n of cold seldom or never takes place during com-
on, except when the specific caloric is suddenly
sed by the conversion of a Solid into a Liquid, or a
d into a Gas. All the frigorific mixtures act in this

. The changes of form that attend Chemical
ı are exceedingly various. The combination of
ı may give rise to a Liquid or a Solid; Solids some-
become Liquids, or Liquids solid. Several familiar
ical phenomena, such as explosions, effervescence,
precipitations, are owing to these changes. The
n evolution of a large quantity of Gaseous matter
ions an *explosion*, as when gunpowder detonates.
slower disengagement of a Gas causes *effervesence*,
curs when marble is put into Muriatic Acid. A
itate is owing to the formation of a new body,
ı happens to be insoluble in the Liquid in which
ments were dissolved.

. The colour of a compound is frequently quite
ent from that of the substances which form it.
ı does not appear to be any uniform relation be-
ı the colour of a body and that of its elements, so
t is not possible to anticipate the colour of any
ular compound, by knowing the principles which enter into its composition. Iodine, whose vapour is of a violet hue, forms a beautiful red compound with mercury, and a yellow one with lead. The brown oxide of copper generally gives rise to green and blue coloured Salts; while the Salts of the oxide of lead, which is itself yellow, are for the most part colourless. The colour of precipitates is a very important study, as it often enables the Chemist to distinguish bodies from one another when in solution."

On the Changes of Circumstances that modify and influence the Operation of Affinity.

" Of the conditions which are capable of promoting or counteracting the tendency to Chemical attraction, the following are the most important; Cohesion, Elasticity, Quantity of Matter, and Gravity. To these may be added the agency of the imponderables.

Cohesion. " The first and obvious effect of cohesion is to oppose Affinity, by impeding or preventing that mutual penetration and close proximity of the particles of different bodies, which is essential to the successful exercise of their attraction. For this reason bodies seldom act Chemically in their solid state; their molecules do not come within the sphere of attraction, and, therefore, combination cannot take place, although their affinity may in fact be considerable. Liquidity, on the contrary, favours Chemical action, it permits the closest possible approximation, while the cohesive power is comparatively so trifling as to oppose no appreciable barrier to Affinity.

" Cohesion may be diminished in two ways; either by mechanical division, or by the application of heat. The former is useful by increasing the extent of surface; but it is not of itself in general sufficient, because the particles, however minute, still retain that degree of cohesion which constitutes solidity. Caloric acts with greater effect, and never fails in promoting combination whenever the cohesive power is a barrier to it. Its intensity should always be so regulated as to produce liquefaction. It is often enough to liquefy one of the substances, as is proved by the facility with which water dissolves many Salts and other solid bodies. But it is easy to perceive that the cohesive power is still in operation; for a Solid is commonly dissolved in greater quantity when its cohesion is diminished by caloric. The reduction of both substances to the liquid state is the best method for insuring Chemical action. The slight degree of Cohesion possessed by Liquids, does not appear to cause" much if " any impediment to combination."

The force of Cohesion frequently performs an important part in modifying the Physical results which Chemical Affinity would of itself produce. The forms of such products seem to depend upon the resultant of two forces not necessarily, but very frequently, opposed to each other. The one Cohesion tending to exhibit the molecules of a substance in the solid form; the other Affinity between the same molecules and a Liquid, tending to produce a compound Fluid. In some cases the former force predominates, as when Muriatic Acid, Sulphuric Acid, and baryta are mixed together, producing solid sulphate of baryta separated from the Liquid. But in other cases the resultant is determined in favour of the latter force; as when Muriatic Acid, Carbonic Acid, and lime are mixed together, producing a Fluid containing some of all the three ingredients, though Carbonic Acid and lime form a Solid. The same views we conceive are applicable to the case of four or more ingredients. It may be just to state that these opinions are not those of Dr. Turner, to whose Work we are on these points so much indebted, and to which we shall shortly return.

Crystallization.

Crystallization appears to be only a modification of the ordinary cohesion of Solids; it probably depends on molecular polarity. A Fluid may contain a certain quantity of a Solid in solution; but let a portion of the Liquid be evaporated, so that the quantity of the Solid remains, while the quantity of Fluid is diminished. At a certain period in this process the Affinity of the Liquid for the Solid, is in equilibrium with the force of cohesion between the molecules of the Solid; but let the evaporation be continued, the latter force will preponderate, and then the particles of the Solid will cohere. In some cases the resulting Solid will present a crystalline form; but in others it will be only a powder. This difference in result arises from the nature of the attraction with which its molecules are endued; but as far as Affinity is concerned, the cohesive force opposed to it differs not in kind, though it may possibly differ in intensity. With the measure of such difference we are at present unacquainted. Generally speaking, crystalline bodies are more soluble than those that are not so, but this rule is not invariable, and in many cases the increase of solubility depends greatly upon water of crystallization.

Elasticity.

"From the obstacle which cohesion puts in the way of Affinity, the Gaseous state, in which the cohesive power is wholly wanting, might be expected to be peculiarly favourable to Chemical action. The reverse, however, is the fact. Bodies evince little disposition to unite when presented to each other in the elastic form. Combination does indeed sometimes take place, in consequence of a very energetic attraction; but examples of an opposite kind are much more common. Oxygen and hydrogen, and chlorine and hydrogen, though their mutual Affinity is very powerful, may be preserved together for any length of time without combining. The cause of this is obviously the distance between the particles preventing that close approximation which is so necessary to the successful exercise of Affinity. Hence many Gases cannot be made to unite directly; which nevertheless combine readily while in their nascent state; that is while in the act of assuming the Gaseous form by the decomposition of some of their solid or fluid combinations.

"Elasticity operates likewise as a decomposing agent. If two Gases whose reciprocal attraction is feeble, suffer considerable condensation when they unite, the compound will be decomposed by very slight causes. The chloride of nitrogen, which is an oil-like Liquid, composed of the two Gases chlorine and nitrogen, answers this description completely, and it is remarkable for being the most explosive substance hitherto discovered. A slight elevation of temperature, by increasing the natural elasticity of the Gases, or the contact of substances which have an Affinity for either of them, produces an immediate explosion.

"Many familiar phenomena of decomposition are owing to Elasticity. All compounds that contain a volatile and a fixed principle are liable to be decomposed by a high temperature." This statement has been objected to (*m*), and with reason, if by "liable to" we are to understand "certain to;" but, probably, the meaning is only that a tendency thence results, which in some cases may produce decomposition, but in others does not so. In the Review by which the objection is advanced the following apposite cases are cited, *viz.* that hydrate of copper is decomposed by a red heat, while hydrate of potash is not so. The compound of chloride of phosphorus and ammonia, which contains three elementary Gases, and a very volatile Solid, is not only very difficult of decomposition, but is not volatilized at a red heat. Where, however, decomposition does occur we may return to Dr. Turner's explanation of the process. "The expansion occasioned by caloric removes the elements of the compound to a greater distance from one another, and thus, by diminishing the force of Chemical attraction, favours the tendency of the volatile principle to assume the form which is natural to it. Many solid substances which contain water in a state of intimate combination, part with it in a strong heat, in consequence of the volatile nature of that Liquid. The separation of oxygen from some metals by heat alone, is explicable on the same principle.

"It appears from these and some preceding remarks, that the influence of caloric over Affinity is variable; for at one time it promotes Chemical union, and opposes it at another. Its action, however, is always consistent. Whenever the cohesive power is an obstacle to combination, caloric favours Affinity, as by diminishing the cohesion of a Solid, or by converting a Solid into a Liquid. As the cause of the Gaseous state, on the contrary, it keeps particles at a distance which would otherwise unite; or by producing expansion, it tends to separate substances from one another, which are already combined. There is one effect of caloric which seems somewhat anomalous; namely, the combination of Gases on the approach of flame. The explanation given of it by Berthollet is, probably, correct,—that the sudden dilatation of the Gases in the immediate vicinity of the flame, acts as a violent compressing power to the contiguous portions, and thus brings them within the sphere of their attraction.

"The influence of quantity of Matter over Affinity is universally admitted. If one body A unites with another body B in several proportions, that compound will be most difficult of decomposition which contains the smallest quantity of B. Of the three oxides of lead, for instance, the peroxide parts most easily with its oxygen by the action of caloric; a higher temperature is required to decompose the deutoxide, and the protoxide will bear the strongest heat of our furnaces without losing a particle of its oxygen.

"The influence of quantity over Chemical attraction may be further illustrated by the phenomena of solution. When equal weights of a soluble Salt are added in succession to a given quantity of water, which is capable of dissolving almost the whole of the Salt employed, the first portion of the Salt will disappear more readily than the second, the second than the third, the third than the fourth, and so on. The affinity of the water for the saline substance diminishes with each addition, till at last it is weakened to such a degree as to be unable to overcome the cohesion of the Salt. The process then ceases, and a saturated solution is obtained.

"Quantity of Matter is employed advantageously in many Chemical operations. If, for instance, a Chemist is desirous of separating an Acid from a metallic oxide by means of the superior Affinity of potash for the former, he frequently uses rather more of the Alkali than is sufficient for neutralizing the Acid. He takes the precaution of employing an excess of Alkali, in order the ry.

more effectually to bring every particle of the substance to be decomposed in contact with the decomposing agent.

"But Berthollet has attributed a much greater influence to quantity of Matter. It was the basis of his doctrine, developed in the *Statique Chimique*, that bodies cannot be wholly separated from each other by the affinity of a third substance for one element of a compound; and to explain why a superior Chemical attraction does not produce the effect which might be expected from it, he contended that quantity of Matter compensated for a weaker affinity. From the cooperation of several disturbing causes, Berthollet perceived that the force of Affinity cannot be estimated with certainty by observing the order of decomposition; and he, therefore, had recourse to another method. He set out by supposing that the Affinity of different Acids for the same alkali is in the inverse ratio of the ponderable quantity of each, which is necessary for neutralizing equal quantities of the alkali. Thus, if two parts of one Acid A, and one part of another Acid B, are required to neutralize equal quantities of the alkali C, it was inferred that the Affinity of B for C was twice as great as that of A. He conceived further, that as two parts of A produce the same neutralizing effect as one part of B, the attraction exerted by any alkali towards the two parts of A ought to be precisely the same as for the one part of B; and he hence concluded that there is no reason why the alkali should prefer the small quantity of one to the large quantity of the other. On this he founded the principle that quantity of Matter compensates for force of attraction.

"Berthollet has here obviously confounded two things, namely, force of attraction and neutralizing power, which are really different, and ought to be held distinct. The relative weights of muriatic and sulphuric Acids required to neutralize an equal quantity of any alkali, or, in other words, their capacities of saturation, are as 37 to 40, a ratio which remains constant with respect to all other alkalis. The Affinity of these Acids will, according to Berthollet's rule, be expressed by the same numbers. But in taking this estimate we have to make three assumptions, all of which are disputable. There is no proof, in the first place, that muriatic Acid has a greater Affinity for an alkali, such as potash, than sulphuric Acid. Such an inference would be directly opposed to the general opinion founded on the order of decomposition; and though that order is by no means a satisfactory test of the strength of Affinity, it would be improper to adopt an opposite conclusion without having good reasons for doing so. Secondly, were it established that muriatic Acid has the greater Affinity, it does not follow that the attraction of these Acids for potash is in the ratio of 37 to 40. And, thirdly, supposing this point settled, it is very improbable that the ratio of their Affinity for one alkali will apply to all others; analogy would lead us to anticipate the reverse. Independently of these objections, M. Dulong has found that the principle of Berthollet is not in accord with the results of experiment.

"Though this mode of determining the relative forces of Affinity cannot be admitted, it is possible that quantity of Matter may, some how or other, compensate for a weaker Affinity, and Berthollet attempts to prove it by experiment. On boiling the sulphate of baryta with an equal weight of pure potash, the alkali is found to have deprived the baryta of a small portion of its Acid; and on treating oxalate of lime with nitric Acid, some nitrate of lime is generated. As these partial decompositions are contrary to the supposed order of elective Affinity, it was conceived that they were produced by quantity of Matter acting in opposition to force of attraction. But they by no means justify such a conclusion. In the decomposition of sulphate of baryta by potash, no care was taken to exclude the atmospheric air during the operation; the alkali must consequently have absorbed carbonic Acid; and it is an established fact, that carbonate of potash decomposes partially the sulphate of baryta. A similar omission appears to have been made in the other experiments, where decomposition was attempted by pure potash or soda. In many cases the result may fairly be attributed to other causes. A circumstance that influences the result of such experiments, and which Berthollet left out of view entirely, is the affinity of Salts for one another. On the whole therefore, we may infer that Berthollet has given no satisfactory case in which quantity of Matter is proved to compensate for a weaker Affinity. Saline substances indeed seem ill adapted to such researches. For it is impossible in many, if not in most cases, to decide upon the relative strength of attraction of two Acids for an alkali, or of two alkalis for an Acid, which, nevertheless, is an important element in the inquiry; and even did we possess such knowledge, the influence of modifying circumstances is such, that it is difficult to appreciate the share they may have in producing a given effect.

Part II.

Gravity.

"The influence of Gravity is perceptible when it is wished to make two substances unite, the densities of which are different. In a case of simple solution, a larger quantity of saline matter is found at the bottom than at the top of the Liquid, unless the solution shall have been well mixed subsequently to its formation. In making an alloy of two metals which differ from one another in density, a larger quantity of the heavier metal will be found at the lower than in the upper part of the compound, unless great care be taken to counteract the tendency of Gravity by agitation. This force obviously acts, like the cohesive power, in preventing a sufficient degree of approximation.

Imponderables.

(114.) The agency of Caloric, Light, Electricity and Magnetism upon Chemical Affinity has been already generally adverted to. See (5.)—(40.)

On the Measure of Affinity.

"As foregoing observations prove that the order of decomposition is not always a satisfactory measure of Affinity, it becomes a question whether there are any means of determining the comparative forces of Chemical attraction. When no disturbing causes operate, the phenomena of decomposition afford a sure criterion; but when the conclusions obtained in this way are doubtful, assistance may be frequently derived from other sources. The surest indications are procured by observing the tendency of different substances to unite with the same principle, under the same circumstances, and subsequently by marking the comparative facility of decomposition when the compounds so formed are exposed to the same decomposing agent. Thus on exposing gold, lead, and iron to air and moisture, the iron rusts with great rapidity, the lead is only tarnished, and the silver retains its lustre. It is hence inferred that iron has the greatest Affinity for oxygen, lead next, and silver least." This conclusion is supported by concurring observations of a like nature, and confirmed by the circumstances under which the oxides of those metals part with their oxygen. The oxide of silver is reduced by heat alone; and the oxide of lead is decomposed by charcoal at a lower temperature than the oxide of iron.

"It is inferred from the action of caloric on the carbonates of potash, baryta, lime, and the oxide of lead, that potash has a stronger attraction for carbonic Acid than baryta, baryta than lime, and lime than the oxide of lead. The Affinity of different substances for water may be determined in a similar manner.

"Of all Chemical substances our knowledge of the relative degrees of attraction of the Acids and alkalis for each other is the most uncertain. Their action on one another is affected by so many circumstances, that it is in most cases impossible, with certainty, to refer any effect to its real cause. The only methods that have been hitherto devised for remedying this defect are those of Berthollet and Kirwan. Both of them are founded on the capacities of saturation; and the objections which have been urged to the rule suggested by the first Philosopher, apply equally to that proposed by the second. But this uncertainty is of no great consequence in practice. We know perfectly the order of decomposition, whatever may be the actual forces by which it is effected.

On the Proportions in which bodies unite, and on the Laws of Combination.

(115.) "The study of the proportions in which bodies unite naturally resolves itself into two parts. The first includes compounds whose elements appear to unite in a great many proportions; the second comprehends those, the elements of which combine in a few proportions only.

I. "The compounds contained in the first division are of two kinds. In one, combination takes place unlimitedly in all proportions; in the other, it occurs in every proportion within a certain limit. The union of water with alcohol and the liquid Acids, such as the sulphuric, muriatic, and nitric Acids, are instances of the first mode of Combination; the solutions of Salts in water are examples of the second. One drop of sulphuric Acid may be diffused through a gallon of water, or a drop of water through a gallon of the Acid; or they may be mixed together in any intermediate proportions, and in each case they appear to unite perfectly with one another. A hundred grains of water, on the contrary, will dissolve any quantity of sea salt which does not exceed forty grains. Its dissolving power then ceases, because the cohesion of the Solid becomes comparatively too powerful for the force of affinity. The limit to Combination is, in such instances, owing to the cohesive power; and but for the obstacle which it occasions, the salt would, most probably, unite with the water in every proportion.

"All the substances that unite in many proportions, give rise to compounds which have this common character, that their elements are united by a feeble affinity, and preserve when combined more or less of the properties which they possess in a separate state. In a Scientific point of view, these Combinations are of minor importance; but they are exceedingly useful as instruments of research. They enable the Chemist to present bodies to one another, under the most favourable circumstances possible for acting with effect; the liquid form is thus communicated to them, while the affinity of the solvent or menstruum, which holds them in solution, is not sufficiently powerful to interfere with their attraction for one another.

II. "The most interesting series of compounds is produced by substances which unite in a few proportions only; and which, in combining, lose more or less completely the properties that distinguished them when separate. Of these bodies, some form but one Combination. Thus there is only one compound of zinc and oxygen, or of chlorine and hydrogen. Others combine in two proportions. For example, two compounds are formed by copper and oxygen, or by hydrogen and oxygen. Other bodies again unite in three, four, five, or even six proportions, which is the greatest number of compounds that any two substances are known to produce, excepting those which belong to the first division.

"The Combination of substances that unite in a few proportions only, is regulated by three remarkable laws. The first of these laws is, that the composition of bodies is fixed and invariable; that a compound substance, so long as it retains its characteristic properties, must always consist, of the same elements united together in the same proportion. Sulphuric Acid, for example, is always composed of sulphur and oxygen, in the ratio of 16 parts (by weight) of the former to 24 of the latter: no other elements can form it, neither can its own elements in any other proportion form it. Water, in like manner, is formed of 1 part of hydrogen and 8 of oxygen; and were these two elements to unite in any other proportion, some new compound different from water would be the product. The same observation applies to all other substances, however complicated, and at whatever period they were produced. Thus sulphate of baryta, whether formed Ages ago by the hand of nature, or quite recently by the operations of the Chemist, is always composed of 40 parts of sulphuric Acid and 78 parts of baryta. This law, in fact, is universal and permanent. Its importance is equally manifest. It is the essential basis of Chemistry, without which the Science itself could have no existence.

"Two views have been proposed by way of accounting for this law. The explanation now universally given of it is confined to a mere statement, that substances are disposed to combine in those proportions to which they are so strictly limited, in preference to any others; it is regarded as an ultimate fact, because the phenomena are explicable on no other known principle. A different doctrine was advanced by the celebrated Berthollet, in his *Statique Chimique*, published in 1803. Having observed the influence of cohesion and elasticity in modifying the action of affinity, as already described, he thought he could trace the operation of the same causes in producing the effect at present under consideration. Finding that the solubility of a Salt and of a Gas in water was limited in the first by cohesion, and in the second by elasticity, he conceived that the same forces would account for the unchangeable composition of certain compounds. He maintained, therefore, that within certain limits, bodies have a tendency to unite in every proportion; and that Combination is never definite and invariable, except when rendered so by the operation of modifying causes, such as cohesion, insolubility, elasticity, quantity of Matter, and the like.

Thus, according to Berthollet, sulphate of baryta is composed of 40 parts of sulphuric Acid and 78 of baryta, not because these substances are disposed to unite in that ratio rather than in any other, but because the compound so constituted has a great cohesive power.

"These opinions, which, if true, would shake the whole Science of Chemistry to its foundation, were founded on observation and experiments, supported by all the ingenuity of that highly gifted Philosopher. They were ably and successfully combated by Proust, in several Papers published in the *Journal de Physique*, wherein he proved that the metals are disposed to combine with oxygen and with sulphur only in one or two proportions, which are definite and invariable. The controversy which ensued between these eminent Chemists on that occasion, is remarkable for the moderation with which it was conducted on both sides, and has been properly quoted by Berzelius as a model for all future controversialists. How much soever opinion may have been divided upon this important question at that period, the dispute is now at an end. The infinite variety of new facts, similar to those observed by Proust, which have since been established, has proved beyond a doubt that the leading principle of Berthollet is quite erroneous. The tendency of bodies to unite in definite proportions only, is indeed so great as to excite a suspicion that all substances combine in this way; and that the exceptions thought to be afforded by the phenomena of solution, are rather apparent than real; for it is conceivable that the apparent variety of proportion noticed in such cases may arise from the mixture of a few definite compounds with each other.

"The second law of Combination is still more remarkable than the first. It has given plausibility to an ingenious hypothesis concerning the ultimate particles of matter, called the Atomic Theory. The law itself, however, contains nothing hypothetical, being the pure expression of a fact first established by Mr. Dalton, and subsequently by many other Chemists. The nature of it will be at once understood by a simple perusal of the following table:

Water is composed of	hydrogen	1	+	oxygen	8
Deutoxide of hydrogen	ditto	1	+	ditto	16
Carbonic oxide......	carbon	6	+	ditto	8
Carbonic Acid	ditto	6	+	ditto	16
Hyposulphurous Acid.	sulphur	16	+	ditto	8
Sulphurous Acid	ditto	16	+	ditto	16
Sulphuric Acid......	ditto	16	+	ditto	24
Nitrous oxide.......	nitrogen	14	+	ditto	8
Nitric oxide........	ditto	14	+	ditto	16
Hyponitrous Acid....	ditto	14	+	ditto	24
Nitrous Acid........	ditto	14	+	ditto	32
Nitric Acid.........	ditto	14	+	ditto	40

"Now it will be perceived that in all these compounds, the numbers denoting the oxygen, which is attached to a given weight of the same base, bear a very simple ratio to one another. The deutoxide of hydrogen contains just twice as much oxygen as water does. The oxygen in carbonic Acid is double that of carbonic oxide. The oxygen in the compounds of nitrogen and oxygen is in the ratio of 1, 2, 3, 4, and 5. So obvious, indeed, is this law, that it is observed at once when we compare the result of a few accurate analyses together; and the only subject of surprise is, that it was not discovered before. It is by no means confined to the compounds of combustibles with oxygen. Thus the sulphur in the two sulphurets of mercury, the chlorine in the two chlorides of mercury, is as 1 to 2. It extends also to the Salts. The bicarbonate of potassa, for example, contains twice as much carbonic Acid as the carbonate; and the oxalic Acid of the three oxalates of potassa is in the ratio of 1, 2, and 4. We must regard it, therefore, as a general law, the enunciation of which may be stated in the following terms. When two substances, A and B, unite chemically, the quantities of the two bodies must either be equal, or in the ratio of multiples or submultiples of each other. It is often called the law of multiples, or of Combination in multiple proportion.

"Every one who hears this singular law announced for the first time, will naturally inquire if it really holds good in all cases. It may be stated in reply, that the examination of numerous compound bodies leaves no room to question the universality of the law; but that it is impossible from the present condition of the Science that every instance should be in accord with it. Two causes are in operation which tend to prevent such perfect coincidence. In the first place, we are not yet acquainted with all possible combinations; and secondly, our knowledge of the composition of known substances is not always precise; circumstances which will not excite surprise when it is considered, that the Science of Chemistry itself, and especially the Art of making accurate analyses, is of very recent origin. The mode in which the first cause operates is obvious: the effect of the second may be illustrated by a few examples. A few years ago Chemists were acquainted with only two compounds of sulphur and oxygen, the sulphurous and sulphuric Acids; the former of which is composed of 16 sulphur and 16 oxygen, and the latter of 16 sulphur and 24 oxygen. The quantity of oxygen combined with the same weight of sulphur in these compounds is in the ratio of 2 to 3. But this exception to the law of multiples was only apparent, arising from our ignorance of the hyposulphurous Acid, a compound which was first noticed by Gay Lussac in the year 1818. It is composed of 16 parts of sulphur and 8 of oxygen, so that the oxygen in the three compounds is as 1, 2, and 3. Arsenic affords an example of the same kind, in which, however, the anomaly is not yet explained. We know only two combinations of arsenic and oxygen which are thus constituted:

	Arsenic.		Oxygen.
Arsenious Acid......	38	+	16
Arsenic Acid........	38	+	24

in which the oxygen is as 2 to 3. But we may confidently expect, on two grounds, that an oxide of arsenic will hereafter be discovered; first, because there is the analogous case of sulphur to justify such a supposition; and, secondly, because arsenic may be expected to form, like the other metals, a salifiable base with oxygen. The three compounds of oxygen and lead are composed of

	Lead.		Oxygen.
Protoxide......................	104	+	8
Deutoxide (hemideutoxide, E. M.)..	104	+	12
Peroxide (deutoxide, E. M.)	104	+	16

and the proportion of oxygen, therefore, is as 1, $1\frac{1}{2}$, and 2. But it is manifest that the discovery of an oxide formed of 104 to 4 of oxygen, would at once make these compounds harmonize with Mr. Dalton's law.

"The third law of Combinations is as fully as remarkable as the preceding, and is intimately connected with it. Water and hyposulphurous Acid may be adduced by way of illustration. The former is composed of 8 oxygen + 1 hydrogen; the latter of 8 oxygen + 16 sulphur. Now it is singular, that the well-known substance, sulphuretted hydrogen, is constituted of 1 hydrogen + 16 sulphur; that is, the quantities of hydrogen and of sulphur, which combine with the same quantity of oxygen, combine with one another. Again, 40 parts of selenium with 8 of oxygen form the oxide of selenium, and with 1 of hydrogen, seleniuretted hydrogen: 36 parts of chlorine with 8 of oxygen constitute the oxide of chlorine, and with 1 of hydrogen form muriatic Acid Gas; 16 parts of sulphur combine with 36 of chlorine to form the chloride of sulphur.

"It is manifest from these examples, that bodies unite according to proportionable numbers; and hence has arisen the use of certain terms, as proportion, combining proportion, or equivalent, to express them. Thus the combining proportions of the substances just alluded to are

Hydrogen	1
Oxygen	8
Sulphur	16
Chlorine	36
Selenium	40

"When one body combines with another in more than one proportion, then the law of multiples already explained comes into action. Thus,

	Sulphur.		Oxygen.
Hyposulph. Acid is composed of	16 or 1 pr.	+	8 or 1 pr.
Sulphurous Acid	16 or 1 pr.	+	16 or 2 pr.
Sulphuric Acid	16 or 1 pr.	+	24 or 3 pr.

"The most common kind of combination is one proportion of one body either with one or with two proportions of another. Combinations of 1 + 3, or 1 + 4, are very uncommon, unless the more simple compounds likewise exist. Ammonia, however, is a singular instance of the reverse. It is composed of nitrogen 14 parts + hydrogen 3 parts. Now, 14 is the precise quantity of nitrogen which unites with 8 of oxygen; and, therefore, 14 is considered as one proportion of nitrogen, which is consequently combined with three proportions of hydrogen. It is probable that compounds of 1 + 1 and 1 + 2 will hereafter be discovered, but they are quite unknown at present.

"But this law does not apply to elementary substances only, since compound bodies have their combining proportions, which may likewise be expressed in numbers. Thus, since water is composed of one proportion, or 8 of oxygen, and one proportion, or 1 of hydrogen, its combining proportion is 9. The proportion of sulphuric Acid is 40, because it is a compound of one proportion, or 16 of sulphur, and three proportions, or 24 of oxygen: and in like manner the combining proportion of muriatic Acid is 37, because it is a compound of one proportion, or 36 of chlorine, and one proportion, or 1 of hydrogen. The proportional number of potassium is 40, and as that quantity combines with 8 of oxygen to form potash, the combining proportion of potash is 48. Now when these compounds unite, one proportion of the one combines with one, two, three, or more proportions of the other, precisely as the simple substances do. The hydrate of potash, for example, is constituted of 48 potash and 9 of water, and its combining proportion is consequently 48 + 9 = 57. The sulphate of potash is composed of 40 sulphuric Acid + 48 potash; and the muriate of the same alkali of 37 muriatic Acid + 48 potash. The combining proportion of the former Salt is, therefore, 88, and of the latter 85.

"The composition of the Salts affords a very neat illustration of this subject; and to exemplify it still further, a list is subjoined of the proportional numbers of a few Acids and alkaline bases.

Fluoric Acid......	10	....	Lithia......	18
Phosphoric Acid ..	28	....	Magnesia ...	20
Muriatic Acid	37	....	Lime	28
Sulphuric Acid....	40	....	Soda	32
Nitric Acid	54	....	Potash......	48
Arsenic Acid	62	....	Strontia.....	52
			Baryta......	78

"It will be seen at a glance, that the neutralizing power of the different alkalis is very different; for the proportion of each base expresses the precise quantity required to neutralize a proportion of each of the Acids. Thus, 18 of lithia, 32 of soda, and 78 of baryta, combine with 10 of fluoric Acid, forming the neutral fluates of lithia, soda, and baryta. The same fact is obvious with respect to the Acids; for 28 of phosphoric, 40 of sulphuric, and 62 of arsenic Acid, unite with 28 of lime, forming a neutral phosphate, sulphate, and arseniate of lime.

"These circumstances afford a ready explanation of a curious fact, first noticed by the Saxon Chemist Wenzel; that when two neutral Salts mutually decompose each other the resulting compounds are likewise neutral. The cause of this fact is now obvious. If 88 parts of neutral sulphate of potash are mixed with 132 of the nitrate of baryta, the 78 baryta unite with the 40 sulphuric Acid, and the 54 nitric Acid of the nitrate combine with the 48 potash of the sulphate, not a particle of the Acid or alkali remaining in an uncombined condition.

	Sulphate of potash.	Nitrate of baryta.	
Sulphuric Acid..	40	54	Nitric Acid.
Potash	48	78	Baryta.
	88	132	

"It matters not whether more or less than 88 parts of sulphate of potash are added; if more, a smaller quantity of sulphate of potash will remain in solution; if less, nitrate of baryta will be in excess; but in either case the neutrality will not be affected.

"The utility of being acquainted with these important laws is almost too evident to require mention. Through their aid, and by remembering the proportional numbers of a few elementary substances, the composition of an extensive range of compound bodies may be calculated with facility. By knowing that 6 is the combining proportion of carbon and 8 of oxygen, it is easy to recollect the composition of carbonic oxide and carbonic Acid; the first being 6 carbon + 8 oxygen; and the second 6 carbon + 16 oxygen. Forty is the number of potassium, and potash being its protoxide, is composed of 4 potassium + 8 oxygen. From these few data we know at once the composition of the carbonate and bicarbonate of potash. The first is 22 carbonic Acid + 48 potash; the second, 44 carbonic Acid + 48 potash. This is done with very little effort of the memory; and the assistance derived from the

d will be manifest on comparing it with the com-
practice of setting down the composition in 100

	Carbonic oxide.	Carbonic acid.
Carbon	42.86	27.27
Oxygen	57.14	72.73

	Carbonate of potash.	Bicarbonate of potash.
Carbonic Acid	31.43	47.83
Potash	68.57	52.17

rom the same data, calculations, which would
wise be difficult or tedious, may be made rapidly,
ith ease, without reference to books, and fre-
ly by a simple mental process. The exact quan-
of substances required to produce a given effect can
termined with certainty, thus affording informa-
hich is often necessary to the success of Chemical
ses, and of vast consequence both in the prac-
f the Chemical arts and in the operations of
nacy.

he same knowledge affords a good test to the
t by which he may judge of the accuracy of his
, and even sometimes correct an analysis which
s not the means of performing with rigid precision.
a powerful argument for the accuracy of an ana-
is derived from the correspondence of its result
he laws of Chemical union. On the contrary, if
n an exception to them, we are authorized to re-
it as doubtful, and may hence be led to detect an
the existence of which might not otherwise have
suspected. If an oxidized body is found to con-
ne proportion of the combustible with 7.99 of
n, then the inference is unavoidable, that 8, or
roportion of oxygen, would have been the result,
he analysis been perfect. From the same cause,
scovery of a new compound, whether it has been
d by the Chemist, or exists as a mineral in the
is always interesting: curiosity is excited to ascer-
he ratio of its constituents, and see if it be such as
ing from the established data would lead us to
ture.

he composition of a substance may sometimes be
nined before any analysis of it has been made.
the new alkali lithia was first discovered, Che-
did not possess a sufficient quantity of it for deter-
g analytically how much oxygen it contained. But
nown that the neutral sulphates of the alkalis and
are composed of one proportion of each constitu-
nd that the oxide contains one proportion of oxy-
If it be found, therefore, by analysis, that the
l sulphate of lithia is composed of 40 parts of
ric Acid and 18 of lithia, we conclude, since
one proportion of the Acid, that 18 is the equiva-
r lithia, and that the oxide is formed of 8 oxygen
of lithium.

he method of determining the proportional numbers
e anticipated from what has already been said;
mmencement is made by carefully analyzing a
e compound of two simple substances, which pos-
n extensive range of affinity. No two bodies are
adapted for this purpose than oxygen and hydro-
and that compound is selected which contains the
st quantity of oxygen. Water is such a substance,
is, therefore, regarded as a compound of one
tion of oxygen + 1 proportion of hydrogen. But
is proves that it is composed of 8 parts of the
+ 1 of the latter; by which the relative weights of their proportions are determined; that of oxygen being 8 times heavier than that of hydrogen.

"Some compounds are next examined, which contain the smallest proportion of oxygen or hydrogen, in combination with some other substance, the quantities of each being the smallest that can unite together. Carbonic oxide, with respect to carbon, and sulphuretted hydrogen, with respect to sulphur, answer this description perfectly. The former consists of 8 oxygen and 6 carbon: the latter of 1 hydrogen + 16 sulphur. The proportional number of carbon is, consequently, 6, and of sulphur 16. The proportions of all other bodies may be determined in the same manner.

"Since the proportional numbers merely express the relative quantities of different substances which combine together, it is in itself immaterial what figures are employed to express them. The only essential point is, that the relation should be strictly observed. Thus we may make the combining proportion of hydrogen 10, if we please: but then oxygen must be 80, carbon 60, and sulphur 160. We may call hydrogen 100 or 1000, or, if it were desirable to perplex the subject as much as possible, some high uneven number might be selected, provided the due relation between the different numbers is faithfully preserved. But such a practice would effectually do away with the advantage ascribed to the use of the proportional numbers, and hence it is the object of every one to employ such simple ones, that their relation may be perceived by mere inspection. As the opinion of different Chemists concerning the simplicity of numbers is somewhat at variance, we possess several series of them. Dr. Thomson, for example, makes oxygen 1, so that hydrogen is one-eighth of unity, or 0.125, carbon 0.75, and sulphur 2. Dr. Wollaston, in his scale of Chemical equivalents, fixes oxygen at 10, by which hydrogen is 1.25, carbon 7.5, and so on. According to Berzelius, oxygen is 100. And, lastly, several other Chemists, such as Dalton, Davy, Henry, and others, call hydrogen 1, and, therefore, oxygen 8. One of these series may easily be reduced to any of the others, by an obvious and simple Arithmetical process; and, excepting that of Berzelius, whose numbers are inconveniently high for practice, it is not very material to which of them the preference is given. In this Work the last method is adopted, in consequence of its containing no fractional parts.

On the Atomic Theory of Mr. Dalton.

(116.) "The brief sketch which has been given of the laws of combination, will serve to set the importance of this department of Chemical Science in its true light. It is founded, as will have been seen, on experiment alone, and the laws which have been stated are the pure expression of fact. It is not necessarily connected with any speculation, and may be kept wholly free from it.

"The reason why persons, partially acquainted with the subject, have supposed it to be of an hypothetical nature, is sufficiently obvious. It was impossible to reflect on the regularity and constancy with which bodies obey the laws of proportion, without speculating about the cause of that regularity; and consequently, the facts themselves were no sooner noticed, than an attempt was made to explain them. Accordingly, when Mr. Dalton published his discovery of these laws, he at once incorporated the description of them with his notion of their Physical cause; and even expressed the former in language suggested by the latter. Since that period, though several British Chemists of eminence, and in particular, Dr. Wollaston and Sir H. Davy, have recommended and practised an opposite course, both subjects have been but too commonly comprised under the name of Atomic Theory; and hence it has often happened, that beginners have rejected the whole as hypothetical, because they could not satisfactorily distinguish between what was founded on fact, and what was conjectural. All such perplexity would have been avoided, and this department of the Science have been far better understood, and its value more justly appreciated, had the discussion concerning the atomic constitution of bodies been always kept distinct from what it was intended to explain. When employed in this limited sense, the Atomic Theory may be discussed in a few words.

"Two opposite opinions have long existed concerning the ultimate elements of Matter. It is supposed, according to one party, that every particle of Matter, however small, may be divided into smaller portions, provided our instruments and organs were adapted to the operation. Their opponents contend, on the other hand, that Matter is composed of certain atoms, which are of such a nature as not to admit of further division. These opposite opinions have, from time to time, been keenly contested, and with variable success, according to the acuteness or ingenuity of their respective champions. But it was at last perceived that no positive data existed capable of deciding the question, and its interest, therefore, gradually declined. The progress of modern Chemistry has revived the general attention to this controversy, by affording a far stronger argument in favour of the atomic constitution of bodies than was ever advanced before, and which seems almost irresistible. We have only, in fact, to assume, with Mr. Dalton, that all bodies are composed of ultimate atoms, the weight of which is different in different kinds of Matter, and we explain at once the foregoing laws of Chemical union.

"According to this view, every compound is formed by a combination of the atoms of its constituents. An atom of A may combine with 1, 2, 3, or more atoms of B, an arrangement on which depends the law of multiples. If water, for example, is composed of an atom of hydrogen and an atom of oxygen, it follows that every compound of hydrogen with an additional quantity of oxygen, must contain 2, 3, or more atoms of oxygen; some multiple in a word by a whole number of the quantity of oxygen contained in water. It is equally clear, from this view of the composition of water, that the weight of an atom of oxygen is eight times heavier than an atom of hydrogen. The relative weight of the atoms of other substances may be determined in a similar manner. Thus an atom of carbon is 6 times, an atom of sulphur 16 times, and an atom of chlorine 36 times heavier than an atom of hydrogen; and this explains why they unite with one another in the proportions expressed by those numbers. What are called the proportional numbers are, in fact, nothing else but the relative weights of atoms.

"No one can suppose that the laws of Chemical union are the effect of chance: there must be some cause for them in the nature of the ultimate particles of Matter. This cause, as we have just seen, is completely supplied by the supposed atomic constitution of bodies, which accounts for the phenomena in the most beautiful and consistent manner. So perfect, indeed, is the explanation, that the existence of these laws might have been predicted by the aid of the atomic hypothesis long before they were actually discovered by analysis. But these are not the only arguments which we at present possess in favour of the existence of ultimate indivisible particles of Matter. Dr. Wollaston, in his Paper on the Finite Extent of the Atmosphere, (*Philosophical Transactions*, 1822,) has defended this side of the question on a new and independent principle, and the proof [illegible] has given of the atomic constitution of bodies appears decisive.

"Some Chemists, even without expressly adopting the Atomic Theory itself, have followed Mr. Dalton in the use of the terms *atom* and *atomic weight*, in preference to *proportion*, *combining proportion*, *equivalent*, and others of a like kind. All these appellations, however, have the same signification; and, in using the word atom, instead of the others, it should be held in mind that it merely denotes the proportions in which bodies unite: that it is the expression of a fact which will remain the same, whether the atomic hypothesis which suggested the employment of the term be true or false.

"There is one circumstance which, at the first view, seems hostile to the supposed atomic constitution of Matter. In describing the law of multiples, it was mentioned that the oxygen in the three oxides of lead is the ratio of 1 : 1½ : 2 : so that if we regard the protoxide as composed of one combining proportion of lead to one proportion of oxygen, the second will contain one proportion and a half, or, according to the atomic theory, one atom and a half of oxygen. Now, though the half of a combining proportion may be admitted, the existence of half an indivisible particle of Matter is inconceivable: and this circumstance would be fatal to the Atomic Theory, were there not some satisfactory mode of accounting for it. Several explanations might be brought forward. One of them, as has already been mentioned, rests on the supposition that what is called the protoxide, is, in reality, composed of one atom of lead to two atoms of oxygen; and that the real protoxide has not yet been discovered. Another mode of accounting for the anomaly is, by regarding the present deutoxide as composed of the protoxide and peroxide combined with each other. A third method is, by doubling both elements of the anomalous compound, by which the exact ratio is preserved, and the idea of the fraction of an atom is avoided. Thus the protoxide and peroxide of iron are composed, the first, of one proportion, or 28 of metal + 8 of oxygen, and the second, of 28 of metal + an atom and a half, or 12 of oxygen; or what amounts to the same thing, of 56, or two atoms of iron, to 24, or three atoms of oxygen. These observations prove, that the occurrence of half proportions is not inconsistent with the atomic constitution of bodies; they show that the difficulty is explicable, and probably will, in the progress of discovery, be entirely removed. In the mean time, however, it would be inconvenient to allow any speculative notions on the subject to interfere with actual practice; and, therefore, it is best at once to admit the occurrence of half proportions: and, if any one prefer the term *atom* to *equivalent* or *proportion*, he must submit to the somewhat jarring expression of half an atom.

"Mr. Dalton supposes that the atoms of bodies are spherical, and has invented certain symbols to represent the mode in which he conceives they may combine together." See his *New System of Chemical Philosophy.*

"There are several questions relative to the nature of atoms, most of which will, perhaps, never be decided. Of this nature are the questions which relate to the actual form, size, and weight of atoms, and to the circumstances in which they mutually differ. All that we know with any certainty is, that their weights do differ, and by exact analysis the ratios between them may be determined. The numbers which indicate the combining proportions of bodies, are, in fact, the relative weights of their atoms.

"It is but justice to the memory of the late Mr. Higgins, of Dublin, to state, that he first made use of the atomic hypothesis in Chemical reasonings. In his *Comparative View of the Phlogistic and Antiphlogistic Theories*, published in 1789, he observes, (pp. 36 and 37,) that "in volatile vitriolic Acid a single ultimate particle of sulphur is intimately united only to a single particle of dephlogisticated air; and that in perfect vitriolic Acid, every single particleof sulphur is united to two of dephlogisticated air, being the quantity necessary to saturation:" and he reasons in the same way concerning the constitution of water and the compounds of nitrogen and oxygen. These remarks of Mr. Higgins do not diminish Mr. Dalton's claim of originality. They appear to have been quite unknown to him at the time he published his *New System of Chemical Philosophy:* and indeed they were made in so casual a manner, as not only to escape observation, but to prove that Mr. Higgins himself attached no particular interest to them. Mr. Dalton's real merit lies in the discovery of the laws of combination, a discovery which is solely and indisputably his; but in which he would have been anticipated by Mr. Higgins, had that Chemist perceived the importance of his own opinions. The merit of applying the atomic hypothesis to account for these laws likewise belongs to Mr. Dalton; nor is his ingenuity in the least affected by the circumstance that another person had previously explained insulated Chemical facts on the same principle.

On the Theory of Volumes.

(117.) "Soon after the publication of the *New System of Chemical Philosophy* in 1808, in which Work Mr. Dalton explained his views of the atomic constitution of bodies, a Paper appeared in the second volume of the *Mémoires d'Arcueil*, by M. Gay Lussac, on the *Combination of Gaseous Substances with each other.* He there proves that Gases unite together by volume in very simple and definite proportions. In the combined researches of himself and M. Humboldt, those gentlemen found that water is composed precisely of 100 measures of oxygen and 200 measures of hydrogen; and M. Gay Lussac, being struck by this peculiarly simple proportion, was induced to examine the combinations of other Gases, with the view of ascertaining if any thing similar occurred in other instances.

"The first compounds which he examined were those of ammoniacal Gas with muriatic, carbonic, and fluoboric Acid Gases. 100 volumes of the alkali combined with precisely 100 volumes of muriatic Acid Gas, and they could be made to unite in no other ratio. With both the other Acids, on the contrary, two distinct combinations were possible. These are:

100	Fluoboric Acid Gas with	100	ammoniacal Gas.
100	Ditto	200	ditto.
100	Carbonic Acid Gas with	100	ditto.
100	Ditto	200	ditto.

"Various other examples were quoted, both from his own experiments and from those of others, all demonstrating the same fact. Thus ammonia was found by M. A. Berthollet to consist of 100 volumes of nitrogen + 300 volumes of hydrogen. 100 volumes of sulphurous Acid and 50 volumes of oxygen produced sulphuric Acid. Carbonic Acid is composed of 50 volumes of oxygen and 100 volumes of carbonic oxide.

"From these and other instances M. Gay Lussac established the fact, that Gaseous substances unite in the simple ratio of 1 to 1, 1 to 2, 1 to 3, &c.; and this original observation has been confirmed by such a multiplicity of experiments, that it may be regarded as one of the best established laws in Chemistry. Nor does it apply to the true Gases merely, but to vapours likewise. For example, sulphuretted hydrogen, sulphurous Acid, and hydriodic Acid Gases are composed of

100 vol. hydrogen	+ 100 vol. vapour	of	sulphur.
100 do. oxygen..	+ 100 do.	do.	do.
100 do...do....	+ 100 do.	do.	iodine.

"There are very good grounds to suppose, also, that solid bodies which are fixed in the fire, would, when in the form of vapour, be subject to the same law. By a method which will be hereafter explained we may calculate what the Specific Gravity of carbon would be, if converted into vapour, and 0.4166 is the number so determined, atmospheric air being unity. Now if we assume that carbonic Acid is formed of 100 volumes of oxygen + 100 volumes of the vapour of carbon, condensed into the space of 100 volumes, the Specific Gravity of carbonic Acid will be 1.1111 (the Specific Gravity of oxygen) + 0.4166 = 1.5277, which is the precise number determined by experiment. Again, it follows from our assumption, that carbonic Acid is composed by weight of

Oxygen 1.1111 ..... 16 or 2 prop.
Carbon 0.4166 ..... 6 or 1 prop.

as ascertained by analysis.

"If we assume that carbonic oxide is composed of 50 volumes of oxygen, and 100 volumes of the vapour of carbon, condensed into the space of 100 volumes, then its Specific Gravity will be 0.5555 (half the Specific Gravity of oxygen) + 0.4166 = 0.9721; and its composition will be

Oxygen 0.5555...... 8 or 1 prop.
Carbon 0.4166...... 6 or 1 prop.

both of which results have been determined by other methods.

"The compounds of carbon and hydrogen are equally illustrative of the same point. If light carburetted hydrogen is formed of 200 volumes of hydrogen + 100 volumes of the vapour of carbon, condensed into 100 volumes, its Specific Gravity should be 0.1388 (twice the Specific Gravity of hydrogen) + 0.4166 = 0.5554; and its composition by weight will be

Hydrogen.... 0.1368...... 2
Carbon...... 0.4166...... 6

"If olefiant Gas is composed of 200 volumes of hydrogen + 200 volumes of the vapour of carbon, its

Specific Gravity will be 0.1388 + 0.8332 = 0.9720; and its composition by weight must be

Hydrogen....0.1388...... 2
Carbon......0.8332......12

both of which results have been obtained by analysis.

"Another remarkable fact established by M. Gay Lussac in the same Paper is that the diminution of bulk which Gases frequently suffer in combining, is also in a very simple ratio. Thus the 4 volumes of which ammonia is constituted, (3 hydrogen + 1 nitrogen,) contract to a half or to 2 volumes when they unite. There is a contraction to two-thirds in the formation of nitrous oxide Gas. The same applies to the combination of Gases and vapours. There is contraction to a half in the formation of sulphuretted hydrogen; and to a third in that of sulphurous acid. The instances just quoted relative to the vapour of carbon confirm the same remark. There is a contraction to two-thirds in carbonic oxide, to a half in carbonic Acid, to a third in light carburetted hydrogen, and to a fourth in olefiant Gas.

"The rapid progress which Chemistry has made within the last few years, is in a great measure attributable to the ardour with which Pneumatic Chemistry has been cultivated. That very department, which at first sight appears so obscure and difficult, has afforded a greater number of leading facts than any other; and the law of Gay Lussac, by giving an additional degree of precision to such researches, as well as from its own intrinsic value, is one of the brightest discoveries that adorn the annals of the Science. The practice of estimating the quantity in weight of any Gas by measuring its volume, of itself susceptible of much accuracy, is rendered still more precise and satisfactory by the operation of this law. It will not, perhaps, be superfluous, therefore, to exemplify the method of reasoning employed in these investigations by a few examples, which will serve, moreover, as a useful specimen to the beginner of the nature of Chemical proof.

"One essential element in every inquiry of this kind, which is indeed the keystone of the whole, is a knowledge of the Specific Gravity of the Gases. But it is exceedingly difficult to determine the Specific Gravity of the Gases with perfect accuracy; for not only do slight alterations of temperature and pressure during the experiment affect the result, but the presence of a little watery vapour, atmospheric air, or other impurity, may cause a material error, especially when the Gas to be weighed is either very light or very heavy. The Specific Gravity of important Gases has accordingly been stated differently by different Chemists, and there is none in regard to which more discordant statements of this fact have been made than of hydrogen Gas. Fortunately we possess the power of correcting the results, and of estimating their accuracy, by means of other data, upon which greater reliance may be placed. According to our best data, the Specific Gravity of oxygen, hydrogen, and nitrogen Gases, air being 1, is

Oxygen............	1.1111
Hydrogen..........	0.0694
Nitrogen...........	0.9722

"It has been proved by analysis that 200 volumes of ammoniacal Gas are composed of 300 volumes of hydrogen and 100 volumes of nitrogen, from which the Specific Gravity of that alkali may be calculated.

Thus, 0.9722 + (0.0694 × 3) = 1.1804,

and 1.1804 ÷ 4 is the Specific Gravity ammoniacal gas should have, did its constituents suffer no contraction; but as they contract to one half, the real Specific Gravity is double what it otherwise would be, or is 0.5902. Now, if by weighing a certain quantity of ammoniacal Gas, the same number is procured for its Specific Gravity, it follows that all the elements of the calculation must have been correct.

"Nitric oxide is composed of 100 volumes of nitrogen + 100 volumes of oxygen, united without any contraction, and forming, consequently, 200 volumes of the compound. Its Specific Gravity must, therefore, be the mean of its constituents, or (1.1111 + 0.9722) ÷ 2 = 1.0416. The coincidence of this calculated result with that determined by weighing the Gas itself, proves that all the data are true. It is obvious, indeed, that the calculated results, as being free from the unavoidable errors of manipulation, must be the most accurate, provided the elements of the calculation may be trusted.

"Dr. Henry has proved by careful analysis that 100 volumes of light, carburetted, hydrogen Gas, a compound of carbon and hydrogen, require 200 volumes of oxygen for complete combustion; that water and carbonic Acid are the sole products; and that the latter amounts precisely to 100 volumes. From these data, the proportions of its constituents and its Specific Gravity may be determined. For 100 volumes of carbonic Acid contain 100 volumes of the vapour of carbon, which must have been present in the carburetted hydrogen, and 100 volumes of oxygen. One half of the oxygen originally employed is thus accounted for, and the remainder must have combined with hydrogen. But 100 volumes of oxygen require 200 volumes of hydrogen for combination, all of which must likewise have been contained in the carburetted hydrogen. The 100 volumes of light carburetted hydrogen submitted to analysis, are hence composed of 100 volumes of the vapour of carbon, and 200 volumes of hydrogen. Its Specific Gravity must, therefore, be 0.5554, that is 0.4166 (the Specific Gravity of carbon vapour) + 0.1388, or twice the Specific Gravity of hydrogen Gas.

"Having ascertained that light carburetted hydrogen Gas is composed of two measures of hydrogen to one of the vapour of carbon, it is easy to calculate the proportion of its constituents in weight. For this purpose we need only multiply the bulk of the Gases by their respective Specific Gravities. Thus, 200 × 0.694 = 13.88, and 100 × 0.4166 = 41.66. Hence, light carburetted hydrogen is composed by weight of

Carbon......	41.66	6
Hydrogen....	13.88	2

"The theory of volumes has very considerable analogy to Mr. Dalton's law of multiple proportions. The former is indeed, to a certain extent, a consequence of the latter; for if one body unites with another in several proportions, the quantities of the variable ingredient will stand in the same relation to one another, when expressed by volume, as they do by weight. But there is one remarkable difference. The weights of the two elements of a compound have no apparent dependence on one another. Thus, 6 carbon and 8 oxygen form carbonic acid; 8 oxygen and 14 nitrogen form nitrous oxide; 8 is no multiple by any whole number of 6; nor 14 of 8. But the elements of a compound are always united by volume, in the ratio of 1 to 1, 1 to 2, 1 to 3, and so on. This distinction is certainly very obvious; but still there is otherwise such a similarity in the two laws, that the peculiar nature of the ultimate particles of Matter which gives rise to the one must surely be the cause of the other. It is to be hoped, therefore, that the connecting link will soon be supplied, and one fact of great interest has already been determined, which may ultimately be of use in accounting for this difference. In the VIth volume of the *Annals of Philosophy*, O. S., Dr. Prout published an Essay *On the Relation between the Specific Gravities of Bodies in their Gaseous state and the Weights of their Atoms*, in which he showed that the atomic weights, or equivalents of several substances, are multiples by a whole number of the atomic weight of hydrogen gas. Dr. Thomson took up this idea, and in his recent admirable Treatise on the *First Principles of Chemistry*, has proved that it applies generally; that the atomic weights of all the simple substances he examined are not only multiples by a whole number of the atomic weight of hydrogen, but with very few exceptions of two atoms of hydrogen.

"Dr. Prout pointed out another circumstance of much interest with respect to this question, in the Paper above alluded to. He showed that in general the Specific Gravity of a body in its gaseous state may be obtained by multiplying its atomic weight (the atom of oxygen being taken as unity) by 0.555, or half the Specific Gravity of oxygen Gas; and Dr. Thomson, in the VIIth chapter of the Work just mentioned, has discussed the subject at considerable length. The following explanation will I hope make the reason of this rule intelligible. Water is composed of one volume of oxygen to two volumes of hydrogen; and as Chemists regard it as a compound of one atom of each element, it, of course, follows that one atom of hydrogen must occupy twice the space of an atom of oxygen. It would be exceedingly convenient, did the atoms of different bodies occupy the same space when in the gaseous form; for then the atoms would be represented by volumes, and the numbers which express the relative weights of the former would be identical with the specific gravities of the gases. But it has been already stated, that an atom of oxygen occupies one half the bulk of an atom of hydrogen; and it follows, therefore, that the Specific Gravity of the former Gas must be twice as great as it would be, did it occupy the same space as the latter. Hence the rule,

as 1 : 0.125 :: 0.5555 : 0.0694,

in which 1 is the atomic weight of oxygen; 0.125 the atomic weight of hydrogen; 0.5555 half the Specific Gravity of oxygen Gas; and 0.0694 the fourth proportional, the Specific Gravity of hydrogen.

"The atoms of several other substances besides hydrogen, occupy in the gaseous state twice the space of an atom of oxygen; indeed, as far as is yet known, every simple substance, though naturally solid, is in this condition, besides the majority of compound Gases; and in all such instances it is easy to calculate the Specific Gravity of a body, by multiplying its atomic weight by 0.5555, or half the Specific Gravity of oxygen. This rule applying only when the weight of the atom is expressed according to the oxygen scale. If hydrogen be represented by unity, then the rule is to multiply 0.5555 by the atomic weight of the body, and divide by 8, the atomic weight of oxygen.

"It appears at first sight to be an easy matter to make the atoms and volumes of bodies correspond to one another; and that it might be effected by considering water as a compound of an atom of oxygen + two atoms of hydrogen. Sir H. Davy has accordingly done so in his *Elements of Chemical Philosophy*, and the atom of oxygen will, therefore, be 16, while that of hydrogen is unity. But the inconvenience arising from this practice is far greater than the evil it was intended to remedy. For on this supposition, sulphuretted hydrogen must be held as an atom of sulphur with two atoms of hydrogen, while it is composed of one volume of each of its constituents. Muriatic Acid Gas would consist of one atom of chlorine, and two atoms of hydrogen, though formed of one volume of each Gas. The same remark applies to Hydriodic Acid, Hydrocyanic Acid, and most other compound Gases containing hydrogen.

"The reason of this is that the atoms and volumes of all the simple Gases, (oxygen excepted,) and many compound ones also, according to the received system, correspond with one another. Sulphuretted hydrogen is composed of one volume or one atom of sulphur to one volume or one atom of hydrogen. Muriatic Acid is composed, in like manner, of one volume or one atom of each of its constituents. Light carburetted hydrogen is a compound of two volumes of hydrogen to one volume of the vapour of carbon, or of two atoms of hydrogen to one of carbon. All this advantage is lost by regarding water as a compound of two atoms of hydrogen to one of oxygen; and this forms a sufficient reason for not adopting the method of Sir H. Davy."

On the Theory of Berzelius.

(118.) "It is well known that the celebrated Professor of Stockholm has for many years devoted himself to the study of the laws of definite proportions, and that he has been led to form a peculiar hypothesis, by way of generalizing the facts which his industry had collected. To give a detailed account of his system does not fall within the plan of this Work: to treat of the atomic theory without alluding to the labours of Berzelius, would, on the other hand, be inexcusable: a middle course will here be adopted by stating briefly the principal opinions of that eminent Chemist, offering at the same time a few comments upon them.

"Berzelius informs us in the Historical introduction to his Treatise on the *Theory of Definite Proportions*, that he commenced his researches on the subject in the year 1807; and that they originated in the study of the Works of Richter. From Richter's explanation of the fact, that when two neutral Salts decompose one another, the resulting compounds are likewise neutral, he perceived that one good analysis of a few Salts would furnish the means of calculating the composition of all others. He accordingly entered upon an inquiry, which was at first limited in its object; but as he proceeded, his views enlarged, and advancing from one step to another, he at length set about determining the laws of combination in general. In perusing his account of the investigation, we are at a loss whether most to admire the number of exact analyses which he performed, the variety of new facts he determined, his acuteness in detecting sources of error, his ingenuity in devising new analytical processes, or the persevering industry which he displayed in every part of the inquiry. But it is at the same time impossible to suppress regret, that instead of forming a complex system of his own, he did not adopt the simple views of Mr. Dalton. This he might have done with very great propriety; since the fundamental laws which he discovered, are, with very little exception, either identical with those previously pointed out by the British Philosopher, or are the direct result of their operation.

"Berzelius assumes with Dalton the existence of ultimate indivisible atoms, to the combination of which with one another the laws of Chemical proportion are owing.

"The first law of Berzelius is the following: 'One atom of one element unites with 1, 2, 3, or more atoms of another element.' This is the grand law of Mr. Dalton, and requires no comment, further than that it has been amply confirmed by the labours of Berzelius. The second is, that 'two atoms of one element combine with three atoms of another.' These are the two laws which regulate the union of simple or elementary atoms.

"The combination of compound atoms with each other obeys another law, and is confined within still narrower limits. 'Two compounds which contain the same electronegative body, always combine in such a manner that the electronegative element of one is a multiple by a whole number of the same element of the other.' Thus, for instance, if two oxidized bodies unite, the oxygen of one is a multiple by a whole number of the oxygen in the other. Various examples may be given of this. The hydrate of potash is composed of

Potash 48, the oxygen of which is 8.
Water 9, the oxygen of which is 8.

"In like manner, if two Acids or two oxides combine the same will be observed.

"In the earthy minerals which contain several oxides, the same law is found to prevail with great uniformity.

"The composition of the Salts, likewise, is under its influence. Carbonate of potash, for example, is composed of

Carbonic Acid 22, the oxygen of which is 16.
Potash ..... 48, the oxygen of which is 8.

And sulphate of potash of

Sulphuric Acid 40, the oxygen of which is 24.
Potash ..... 48, the oxygen of which is 8.

"Berzelius has remarked that the nitrates, phosphates, and arseniates, may prove exceptions to the law in some instances. There is also a similar relation in Salts which contain water of crystallization, between the oxygen of the base of the Salt and that of the water. For instance, crystallized sulphate of soda is composed of

Sulphuric Acid 40.
Soda ...... 32, the oxygen of which is 8.
Water ...... 90, the oxygen of which is 80.

"Double Salts are also influenced by the same law. In the tartrate of potash and soda, for example, the oxygen of the potash is exactly equal to the oxygen in the soda; and the oxygen in the tartaric Acid, which neutralizes the potash, is equal to that of the soda.

"But this is not all that Berzelius has remarked with respect to the constitution of the Salts. He observes, that in each series of Salts the same relation always exists between the oxygen of the Acid and of the base. In all the neutral sulphates this ratio is as three to one; as may be seen in the sulphates of soda and potash. In the carbonates, the oxygen of the Acid is double; and in the bicarbonates quadruple the oxygen of the base.

"The existence of these remarkable laws was discovered by Berzelius at a very early period of his researches; and he mentions, that as subsequent observation during the course of several years has not afforded a single exception to them, he now regards them as universal. He accordingly places unlimited confidence in their accuracy, and is in the constant habit of calculating the composition of bodies on this principle.

"It will, of course, be interesting to inquire into the cause of these phenomena; to ascertain if there is any property peculiar to oxygen, or other negative electrics, which might give rise to them. Berzelius himself says, that 'the cause is involved in such deep obscurity, that it is impossible at the present moment to give a probable guess at it.' I (says Dr. Turner) have the misfortune to differ entirely from Berzelius on this question. So far from being obscure, it is perfectly intelligible, and is precisely what might have been anticipated from the present state of Chemical knowledge. Most of the Salts called neutral sulphates, are composed of one proportion or one atom of sulphuric Acid, and one atom of some peroxide. This is the case with all the alkaline and earthy sulphates, and with several of the common metals, as lead, zinc, and iron. Now an atom of sulphuric Acid is composed of

Sulphur .. 16 .... 1 atom.
Oxygen .. 24 .... 3 atoms.

And every protoxide of

Metal .... 1 atom.
Oxygen .... 8 .... 1 atom.

"Hence a number of laws may be deduced, which must hold in every sulphate of a protoxide.

"1. The oxygen of the Acid is a multiple of that in the base

"2. The Acid contains three times as much oxygen as the base.

"3. The sulphur of the Acid is just double the oxygen of the base.

"4. The Acid itself is five times as much as the oxygen of the base.

"Metallic sulphurets are frequently composed of an atom of each element; and should oxidation ensue, so that the sulphur is converted into sulphuric Acid, and the metal into a protoxide, they will be in the exact proportion for forming a neutral sulphate. Berzelius has proved by analysis that this happens frequently, and he is disposed to convert it into a general law.

"Again, the carbonates are composed of one atom of carbonic Acid, and one atom of some protoxide; but an atom of carbonic Acid is composed of

Carbon.... 6 .... 1 atom.
Oxygen .. 16 .... 2 atoms.

And every protoxide of

Metal .... 1 atom.
Oxygen.... 8 .... 1 atom.

"It is inferred, therefore, that in all the carbonates, the oxygen of the Acid is exactly double that of the base; and the same mode of reasoning is applicable to the various genera of Salts. These few examples erve to show, that what seemed so obscure to lius, is rendered quite obvious by the Daltonian od. We perceive, moreover, that no constant can exist between the quantity of the oxide and f the Acid, or oxygen of the Acid; and the reason cause the atomic weights of the metals are differ- But this view of the subject answers another l purpose; it enables us to see whether the law of lius is or is not universal. The observations made is subject by Dr. Thomson in his *First Principles*, much to the point that they are here given in his words.

Before concluding these general observations,' says homson, 'I may say a few words on Berzelius's that in all Salts the atoms of oxygen in the Acid itute a multiple by a whole number of the atoms ygen of the base. This law was founded upon rst set of exact analyses of neutral Salts which Ber- made. Now, as neutral Salts in general are com- ions of an atom of a protoxide with an atom of id, it is obvious that the atoms of oxygen in the must in all such Salts be multiples of the atom of n in the base; because every whole number is a ple of unity. Neutral Salts, therefore, are not the of Salts by means of which the precision of this sed law can be put to the test.'

Even in the subsalts, composed of one atom of united to two atoms of base, it is obvious enough he law will hold whenever the Acid, combined with ase, happens to contain 2 or 4, or any even num- f atoms, because all even numbers are multiples Now this is the case with the following Acids:

phoric.
onic.
cic.
urous.
Nitrous.
Titanic.
Arsenious.
Selenic.
Antimonic.
Manganesic.
Molybdous.
Uranitic.
Citric.
Saclactic.
Chromous.

equently the law must hold good in all combina- of 1 atom of these Acids with 2 atoms of base. n the case of all these Acids which contain only m of oxygen, all the subsalts composed of one of the Acid united to 2 atoms of the base, the ill also in some sort hold; for the atoms of the n in such Acids being 1, this number will always submultiple of 2, the number of atoms of oxygen toms of base. This is the case with the following .

Silicic.
Phosphorous.
Hyposulphurous.
Oxide of Tellurium

t is only in the subsalts of Acids containing an odd er of atoms of oxygen, that exceptions to the law xist. It is to them, therefore, that we must have rse when we wish to determine whether this em- l law of Berzelius be founded in Nature or not. there are 13 acids, the integrant particles of which in an odd number of atoms of oxygen. The fol- g Table exhibits the names of these Acids, together he number of atoms of oxygen in each.

lphuric Acid....	3	Acetic Acid	3
senic Acid	3	Succinic Acid	3
romic Acid	3	Benzoic Acid	3
olybdic Acid....	3	Nitric Acid	5
ungstic Acid	3	Tartaric Acid	5
alic Acid......	3	Hyposulphuric Acid	$2\frac{1}{2}$
rmic Acid	3		

Dr. Thomson informs us that the number of salts he has examined is exceedingly small, because his 'object was not to investigate the truth of Berzelius's law, but to determine the quantity of water of crystallization which the Salts contain.' He observes that 'it would certainly be a most remarkable circumstance if 2 atoms of any protoxide were incapable of combining with 1 atom of any of the 13 Acids in the preceding list.' Dr. T. adduces seven instances in which this does happen, three of which are completely in point, being a subsulphate of alumina, a subacetate of lead, and a subacetate of copper: and he is 'persuaded that many more will be discovered whenever the attention of Chemists is particularly turned to the subsalts.' He also mentions other kinds of Salts, in regard to which, for equally obvious reasons, the law cannot and does not hold.

"These extracts will suffice for placing the law of Berzelius in its true light; for showing that it is a direct consequence of the general operation of the laws of definite proportion: and that we must expect to find some exceptions to his law, derived from the very cause which gives rise to it. It is to be hoped that Berzelius will take the remarks of Dr. Thomson into mature consideration, by which he will probably perceive that his favourite canon is not so universal as he imagines, and be led to avoid the errors to which, from an indiscriminate employment of it, both himself and his pupils might otherwise be exposed.

"That part of the law which applies to the combined water is likewise more than doubtful. When the base contains 2 atoms of oxygen, and an uneven number of atoms of water are present, it cannot be correct. When the base contains 3 atoms of oxygen, the law would not apply whenever there chanced to be 2, 4, 8, or 10 atoms of water. When the base has only 1 atom of oxygen, then it must hold for obvious reasons. When the base has $1\frac{1}{2}$ atom of oxygen, the law can only be true when 3, 6, 9, or 12 atoms of water are in combination. With 1, 2, 4, 5, 7, 8, or 10 it must fail. The hydrate of the peroxide of iron is an exception of this kind, and similar ones are to be looked for among the crystallized Salts of the peroxide.

"An admirable attempt has been made within this few years to determine the atomic constitution of minerals, in which Berzelius has highly distinguished himself. The composition of minerals must of course be influenced by the usual laws of combination, though there are sometimes obstacles in the way of discovering it. In the compounds made artificially, Chemists possess the power of having each constituent perfectly pure; but unfortunately we cannot always command the same condition with respect to natural productions. The materials of which a mineral is composed, once formed a part of some heterogeneous fluid or semifluid mass, and in assuming the solid form are very likely to have enclosed within them some substance, which, Chemically considered, does not form a part of the mineral. The result of Chemical analysis, accordingly, does not always give us a view of the actual constitution of a mineral species; some substances are often detected which are foreign to it, and the Chemist must exercise his judgment in determining what is and what is not essential. Now nothing is so well calculated to direct him as a knowledge of the laws of combination: but as a great discretionary power is in his hands, it is important that his mode of investigation should be the simplest possible, and that his rules should be founded on well-established principles, which involve nothing hypothetical. It is but very lately that due care has been bestowed in selecting sufficiently pure specimens for examination, or in performing the analyses themselves with the precision necessary for determining the Chemical constitution of minerals. It were much to be wished that our first essays in this difficult field should be confined as much as possible to such minerals as contain but few substances, and which occur in distinct transparent crystals.

"We are indebted to Berzelius for this mode of studying the composition of minerals; and certainly if skill in analytical investigation could encourage any one to make the attempt, none could undertake it with greater chance of success than the indefatigable Professor of Stockholm. Unfortunately his theoretical views are unnecessarily complex, and I much doubt, for reasons already stated, if his ruling law about multiples of oxygen deserves the confidence he bestows upon it. It will not, I am convinced, be adopted by the Chemists and Mineralogists of this Country, and I am much mistaken if, notwithstanding the great reputation of its author, it stand its ground long upon the Continent. To give a particular description of his method is foreign to our purpose, but the reader will find an able account of it in the IXth volume of the *Annals of Philosophy*, New Series, by Mr. Children." (*n*)

(119.) The early Chemical writers were accustomed to represent all the elementary bodies by certain symbols, arbitrarily adopted, and by combinations of these they also expressed the compound substances. Should curiosity lead any one to examine this matter, we refer him to Bergman's Work on *Elective Attractions.*

Professor Berzelius has adopted a method in some respects similar, but in a greatly improved form, more suited to the present state of our Science. His fundamental symbols are formed by adopting the initial or leading letters which commence the Latin name of each substance; and by the help of figures and points, placed like indices over these symbols, he represents the atomic constitution and the degree of oxidation of each substance. It was our original intention to have given a statement of his method, but we fear that want of space may prevent us from so doing. We, therefore, for the present must refer our readers to his *Essai sur la Théorie des Proportions Chimiques*, Paris, 1819, or to Mr. Children's analysis above quoted; but should we find sufficient space, the symbols themselves shall be given in a Tabular form at the end of this Treatise.

(120.) It only now remains, before we proceed to the Chemical properties of bodies, that we should present a diagram of the method according to which each element, whether ultimate or proximate, will be considered.

A. History of discovery, and natural state.

B. How obtained pure; its constitution if a compound.

C. Physical properties.

D. Mutual action with oxygen.

E. Mutual action with chlorine.

F. Mutual action with fluorine.

G. Mutual action with iodine.

H. Mutual action with the nonmetallic electro-positive elements.

I. Mutual action with the metallic electro-positive elements.

K. Mutual action with $\left\{\begin{array}{l}\text{Acids.}\\ \text{bases.}\end{array}\right.$

L. Mutual action with reagents, or distinctive properties.

M. Uses in Medicine and the Arts.

It will be obvious that, by a constant use of the above letters, simplicity of reference will be obtained, and repetitions or confusion will be avoided.

Bromine is not inserted in the above scheme, in consequence of the little that is at present known of its mutual action with other bodies.

References from (41.) to (120.) inclusive.

(*a.*) Faraday, *Journal of Science*, vol. iii. p. 354 and vol. vii. p. 106. (*b.*) *Annales de Chimie et* *Physique*, vol. xvi. p. 129. (*c.*) Professor Thomso *An. Phil.* vol. xvi. (*d.*) Gay Lussac, *An. Phil.* vol. i p. 16. (*e.*) Meinecke, *Jour. of Science*, vol. iii. p. 41 (*f.*) Berzelius and Dulong, *Annales de Chimie et* *Physique*, vol. xv. p. 386. (*g.*) Thomson *on Tr* *Atomic Weights*, p. 62. (*h.*) Thomson, *Annals*, vol. vi. p. 241. (*i.*) Henry, *Chemistry*, vol. i. p. 1 edit. 10. Lavoisier, *Elémens*. (*k.*) Kirwan on the Composition of Acids in his *Essay on Phlogiston.* Berthollet, *Chim. Stat.* Davy, *Elements.* Davy, *Phil. Trans.* 1810. Murray, *Edin. Phil. Trans.* vol. viii. (*l.*) Turner, *Elements of Chemistry*, p. 98. (*m.*) *An. Phil.* N. S. vol. i. p. 380. (*n.*) Turner, *Elements of Chemistry*, p. 148.

CHAPTER II.

Non-Metallic (Electronegative?) Elements.

Of the five substances that come under the above denomination, the two first, oxygen and chlorine, when quite pure, are seen only in the gaseous form at all temperatures with which we are acquainted; though under strong pressure, the latter is a liquid. Fluorine has not as yet been exhibited in an independent form, while iodine and bromine are solid, liquid, or gaseous, according to the temperature at which we examine their properties. Oxygen.

§ 1.—*Oxygen.*

(121.) A. Oxygen Gas may be said to have been first discovered by Dr. Priestley, for on the 1st of August, 1774, he obtained it by exposing the red oxide of mercury to the heat produced by condensing the rays of solar light in the focus of a lens. Thus separated he examined its properties, and named it dephlogisticated air. In the year following, Scheele, without being aware of Priestley's discovery, obtained it by other methods; and by Lavoisier, who undertook a further examination of its properties its present name of oxygen was proposed.

Although the word *Oxygen* stands at the head of this section, we are unable to speak of oxygen in its simple state. It has never yet been seen other than in the gaseous form, when it is supposed to consist of the true base, oxygen, united with caloric. When in combination it frequently loses that form and then becomes a constituent part of solid or liquid substances. It is well to bear in mind this distinction between oxygen

ygen Gas, though the terms are frequently made
indiscriminately; this would not, however, be
e were caloric a ponderable body, for now we
.y, that oxide of zinc consists of 425 parts (by
) of metal united with 100 parts of oxygen, or
;en Gas indifferently.

gen exists in its gaseous state as a constituent
the atmosphere: forming that portion which is
al to animal life and to combustion. Of almost
orm and kind of matter which surrounds us it
ın ingredient. Its compounds are more nume-
ıd diversified than those of any other substance
which we are acquainted. It produces most
al effects in changing the properties of other
bodies with which it combines. Thus when
to azote in one proportion it forms the genial
breathe. Mild and salutary as are the properties
well-known substance, yet if the proportions of
ıbining bodies be changed we have a powerful
Acid—the nitric, capable of dissolving metals
ing as an escharotic on living animal bodies.
ıs a part of every earth we tread upon, and of
egetable we see around us; and when com-
vith another gaseous body, hydrogen, it forms
an important and essential form of food to all
nal and vegetable creation.

.) B. There are several methods by which
Gas may be obtained for experimental pur-

riestley's mode already described. (*a.*)

:heele obtained it by the distillation of nitre.
ethod is still at times resorted to, but such oxy-
ıot very pure. A pound of nitre thus distilled
earthen retort, at a red heat, will yield about
ıbic inches of Gas. (*b.*)

:heele also obtained it from a mixture of black
f manganese and sulphuric Acid. In this pro-
parts of manganese may be mixed with 3 parts
huric Acid, in a glass retort, and the Gas may
ngaged by the heat of an Argand's lamp.

avoisier, who had been informed by Priestley of
ı researches, expelled the oxygen from red oxide
ury by heating it in a retort; and described his
to the Royal Academy in 1755.

he hemideutoxide of lead, minium, or red lead
nerce, gives out pure oxygen Gas by the appli-
of heat and is converted into the protoxide.

ygen Gas is, however, obtained most plentifully
erimental purposes, by placing any quantity of
nmon black oxide of manganese in an iron
r bottle having a tube passing from it into a
ter; this retort is placed in a fire, so as to
a moderate red heat, when the oxygen Gas is
l in considerable quantity.

ut should the Gas be required of great purity it
l to put a small quantity of the chlorate of
into a glass retort, and to apply cautiously a
oderate lamp or sand heat. The Salt first fuses
n gradually parts with a considerable quantity
pure oxygen Gas. In this case the oxygen is
ged from the chloric Acid, which consists of that
ce and chlorine; and also from the potash, which
of oxygen and potassium; so that dry chloride
ssium is the sole residuum found in the retort.

are is necessary in this process, especially if a
lass retort be employed: as the alkaline matter
es with the glass and the bottom of the retort gives way. For this reason it is advantageous to employ a sand-bath in which the retort may be safely supported.

(123.) C. Oxygen Gas thus obtained has the following physical properties. It is without colour. It follows the general laws applying to all gaseous matter with regard to pressure and temperature. (76, and 82.) It is heavier than common air, its Specific Gravity referred to that substance being 1.1111. As 100 cubic inches of dry atmospheric air, thermometer 60° Fahrenheit, barometer 30 inches, weigh 30.5 troy grains, according to Sir G. Shuckburgh, if the above Specific Gravity be correct, (and it rests upon the reasoning of the accurate Dr. Prout, confirmed by the experiments of Professor Thomson,) the same volume of oxygen, *iisdem positis*, will weigh 33.888 grains. It has neither smell nor taste. By a sudden and violent condensation oxygen Gas emits both light and heat. All Gases thus evolve heat upon condensation, but, according to M. Saissy, oxygen, chlorine, and common air are the only Gases that emit light under these circumstances. Of these oxygen emits the most, then chlorine, and, lastly, air. Of all Gases, oxygen has the least refractive power upon light. If the refractive power of air be 1, that of oxygen is 0.8616. Oxygen is more strongly electronegative than any other body at present known. When disengaged from all other substances in Nature by Voltaic electricity, it and its compounds invariably go to the positive pole of the pile.

When oxygen Gas is left in contact with water the quantity of Gas absorbed is scarcely perceptible; but Dr. Henry found that 100 cubic inches of water, which had been freed from all air by boiling and the air-pump, would absorb 3.55 inches of Gas. (*c.*) Saussure estimated that 100 cubic inches would absorb 6.55 cubic inches of Gas, (*d.*) but Dalton considers the former estimate much more accurate. (*e.*)

(124.) E. See chlorine, sect. 2. reference D.

(125.) F. See fluorine, sect. 3. ref. D.

(126.) G. See iodine, sect. 4. ref. D.

(127.) H. Oxygen unites with all the substances falling under this division: it forms compounds of very varied properties. With hydrogen it forms water, chap. iii. sect. 2. subsect. 1. With azote it forms atmospheric air and some strong Acids, chap. iii. sect. 8. subs. 1, 2, 3, 4, and 5. With sulphur it forms Acids, chap. iii. sect. 6. subs. 1, 2, 3, and 4. With selenion it forms a gaseous oxide, chap. iii. sect. 7. subs. 1. With phosphorus it forms acids, chap. iii. sect. 5. subs. 1 and 2. With carbon it forms an oxide and an Acid, chap. iii. sect. 3. subs. 1 and 2. With boron it forms an Acid, ch. iii. sect. 4. subs. 1. And with silicon it forms a compound which on the whole may be considered as having acid properties, chap. iii. sect. 1. subs. 1.

(128.) I. With the metals oxygen invariably unites. In some cases in one proportion only; in others in two or more proportions. Sometimes it is held by a strong affinity, sometimes the affinity is of the feeblest possible kind. From some of these unions with the metals we obtain Alkalis; from others Earths; and from others Acids. These properties will be considered in each individual case under the metals, respectively, but as general views on this subject are of fundamental importance, we offer the following general summary by M. Thenard.

"The phenomena which oxygen Gas presents when in contact with metals are of such importance as to demand our utmost attention. We ought to examine all those causes which may conduce to their production, and register the effects respectively produced by them. These causes, independent of affinity, arise principally from the hygrometric state of the oxygen Gas, and from temperature.

"Dry oxygen Gas at ordinary temperatures is absorbed by potassium; and hence we might be led to conclude that it would be also absorbed by barium, lithium, strontium, calcium, and by the metals of the first section; (*i. e.* those of our chap. iv. class 1.) but at the same temperature it is not absorbed by sodium, nor by any of the metals belonging to the last four sections. A certain elevation of temperature favours this action prodigiously; so that in fact by this mean it may be made to act upon all the metals, with the exception of those of the last section, (class 6.) A considerable number of them absorb oxygen when the temperature is sufficiently elevated, with the evolution of light; *viz.* all the metals of the second class; zinc, iron, tin, and cadmium, in the third; arsenic, antimony, tellarium, bismuth, in the fourth. Tin, antimony, and bismuth being those whose combustion is most feeble. It may seem, perhaps, extraordinary to find tellurium burning with the evolution of light, while manganese, which has much greater affinity for oxygen than it has, does not possess that property. The reason, however, is simply this, that tellurium, being both fusible and volatile, forms, *dato tempore*, a much greater quantity of oxide than manganese which is fixed and almost infusible. In fact, in order that any substance may burn with flame it must not only have a great affinity for oxygen but it must also enter into fusion readily, or be volatile, or rather, perhaps, if the oxide which it forms is readily fusible or volatile: without this, the contact between the substance burning and the substance burned, not being intimate, the combustion cannot be vivid.

"The combination of metals with oxygen Gas may almost always be effected by filling a small retort or bent tube with the Gas, over mercury, and after having introduced a certain quantity of the metal by means of a bent wire, applying the heat of a spirit-lamp and agitating the metal with the wire if necessary. It is only when the heat required is very considerable indeed, that a porcelain tube is employed. This tube containing the metal may pass through a small furnace, and may communicate by means of small glass tubes, at one extremity with an empty bladder, and at the other extremity with a bladder full of oxygen. After the furnace is lighted and the porcelain tube has become white hot, the oxygen Gas is to be passed slowly backward and forward from one bladder to the other several times. The absorption will be entire if there be sufficient metal in the tube.

Action of moist oxygen.

"Oxygen Gas when in a humid state attacks not only the metals of the two first classes, but even many of those belonging to the third, the fourth, and even the fifth class. With regard to the former, oxidation takes place at once at the expense of the free oxygen, and also of the oxygen of the water, which is decomposed and its hydrogen liberated. With regard to the latter, the metal receives only the free oxygen; and in this case we suppose the aqueous vapour to possess a twofold action; on the one hand it may partly become liquid and hold in solution a portion of the oxygen, thus rendering this oxygen, when deprived of its elasticity, more capable of combining with the metal; on the other hand, it may still further promote the combination by its own tendency to unite with the metallic oxide and form an hydrate. Be this as it may, the oxidation so produced is generally only superficial, and is always very slow in its progress: the interior parts of the metal are always protected by the exterior film, or at least a considerable time must elapse before they undergo any considerable alteration. The metals which most readily oxidize in this manner are arsenic, manganese, iron, zinc, lead, copper, &c.; those of the sixth class being unalterable.

Atmo-spheric

"When the oxygen, whether it be dry or moist, is mixed with azote, its action upon the metals is the same as if the azote were not present, except that possibly that action may be less intense; for the azote acts only mechanically by diminishing the points of contact in a given space between the oxygen Gas and the metals. But since atmospheric air is composed of about four-fifths azote and one-fifth oxygen, with a little aqueous vapour and a little carbonic Acid Gas, it ought to act upon metals in the same manner as oxygen does, but with some difference of intensity. This is in fact what happens: when dry, it only attacks at ordinary temperatures the metals of the first two classes, and even is without action upon sodium: when moist, it acts not only upon all these, but also upon many metals of the third, fourth, and fifth classes. Whether dry or moist, it acts upon all by the aid of heat: those of the last class alone excepted. The result of this action is an oxide, or an hydrate. But if the process take place in the open air, the product is frequently a carbonate, especially at common temperatures: thus it is that the air, being perpetually renewed, is continually yielding small quantities of carbonic Acid to the oxide, whenever these two bodies have sufficient affinity to enter into union. Thus brass statues become gradually covered with carbonate of copper; and in leaden reservoirs, there is formed immediately above the surface of the water, not oxide of lead, but carbonate of lead."

"No carbonate can, however, be formed if the temperature be considerably elevated, except those of barium, potassium, sodium, and probably lithium; because all the carbonates decompose at that temperature except those of barytes, potash, soda, and apparently of lithia. (*f.*)

(129.) K. Though it does not immediately appear that any actions of the kind to which this reference applies can be described, yet we are of opinion that, with a due consideration of the mutual agencies of all bodies, it would require only ordinary ingenuity to discover a series of effects which might be ranged under this head: especially if we subscribe to Berzelius's views of the constitution of mineral bodies, and extend them to all substances in Nature.

(130.) L. Oxygen Gas is distinguished from all other bodies by the following properties. It is not inflammable; is not absorbed by a solution of caustic potassa; it is capable of restoring to full combustion a match which has been partially extinguished; it combines by the electric spark with twice its volume of hydrogen, forming water and leaving no gaseous residuum.

(131.) M. Oxygen Gas is essential to the animal economy: and although, from its powerful excitative effects, it cannot be long respired alone with impunity, yet when

ined with four times its volume of azote it forms
›mpound best adapted to our organs of respiration,
ıe air we breathe. If the oxygen be in less pro-
›n, the air is not salubrious, and if totally absent,
ll not support life for a moment. When pure
m Gas is respired, the evil effects of an accelerated
ation arise: the lungs become inflamed and the
› system enters upon a state of fevered excitement.
ıpts have been made to exhibit oxygen in some
of disease, but as yet these have been attended
but slender success. It is not to be understood
ıxygen is the only Gas that can be breathed; but it
only one that can be permanently breathed with-
lerangement of some sort or other arising in the
n. A singular instance of its action has been re-
Three men who were employed in clearing out
ault of a *cabinet d'aisance* at Paris were suffocated
› sulphuretted hydrogen, which always exists abun-
y in such places. When taken out, they were con-
l to the *Hotel Dieu:* two died on the way thither;
ird arrived there alive, but without any power to
his limbs. In the haste to contrive something
should be administered to him, a bladder full of
m presented itself, and he was made to breathe it:
ıan immediately sat up, but again fell down and
ed. It has been supposed that he might have been
ed to life, if a small quantity of chlorine Gas,
l with a considerable quantity of atmospheric air,
een similarly administered to him.

Combustion.

2.) It might not, perhaps, be quite satisfactory
we entirely to omit all consideration of Combus-
and yet we feel that little real knowledge is to be
d by any detailed views of the numerous explana-
that have been proposed on this subject. In the
›lace, the word itself is rather vague in its appli-
ıs by different writers. Originally, Combustion
synonymous with what in common language is
the burning of any thing. The Chemist was
called upon to explain, in the terms of Science,
›nditions, the operations, and the result of that
ss. Subsequently, however, the explanations which
thus given led to a great extension of the applica-
of the dogmás advanced: and the term Combus-
was made use of in cases where burning in its
ıry sense could not be said to exist. If by Com-
›n we mean the union of oxygen with certain
s, attended by the production of light and heat, it
e thing: and in this case mere oxidation is ex-
d. But if we apply the term to any Chemical
e between the elements of Matter, wherein light
ıeat are evolved, it is quite another thing, and
is no essential necessity for the presence of oxygen.
re of opinion that the introduction of confusion is
at is obtained by continuing to employ the word in
ther than a popular sense.
ll it may be necessary, for the information of some,
te that the first Scientific explanation of Combus-
was given by Stahl, who conceived that there ex-
in all combustible bodies a certain elementary
ple which he called *phlogiston,* and that the
ss of Combustion depended upon the evolution of
›rinciple. Thus a body that had been burned or
ted, he termed dephlogisticated, supposing it to have
s phlogiston. The heat and light which accompany Combustion he explained as a consequence of the rapidity with which that principle was evolved. Thus, in truth, substituting a description of what took place, *viz.* the heat and the light, in place of the word Combustion; and affording no real explanation of the process.

The researches of Lavoisier overturned the theory of Stahl, and introduced another explanation of Combustion, resting far more securely upon an experimental basis. Oxygen had recently become known to Chemists, and Lavoisier showed that a dephlogisticated substance had in fact gained something, instead of having parted with something, as Stahl had asserted. He proved that those substances which were capable of Combustion, were to be considered as the more elementary of the two classes: that in the process of burning they gained weight; and that this gain of weight was due to their having taken a quantity of oxygen into combination, which they might, by certain processes, be compelled again to evolve. It only remained that he should, like Stahl, attempt to say why Combustion was attended with heat and light. Dr. Black's doctrines of latent heat and specific caloric seemed to afford a plausible explanation of this circumstance. Lavoisier, therefore, asserted, that in some cases the heat and light were due to the change of Physical state of the combining bodies: as for instance, that when phosphorus was burned in oxygen Gas, the effect was due to the great condensation experienced by the latter, in passing from the gaseous to the solid form. In other cases it was urged that the specific heat of the compound being less than that of the simples, such an evolution must take place. It has, however, been found, that these principles are insufficient to serve for a general explanation of the phenomena of Combustion. All that we now dare to assert is, that great heat, and sometimes light also, is evolved where no oxygen is present: and that intense Chemical action is all that can be supposed to be essentially present in all cases. The experiments of Dulong and Petit have proved that the specific caloric of combining and combined bodies will not afford the explanation thence anticipated by Lavoisier. (*g.*) And as Chemical action or affinity is all that we can recognise in the process, it has been supposed that the heat and light are due to the union of opposite electricities: a supposition that can satisfy those only who, with Davy and Berzelius, believe Chemical affinity to arise only from the opposite electrical states of the molecules of matter. Consult, also, Sir H. Davy's *Memoirs on Flame and Combustion.* (*h.*)

References in Oxygen.

(*a.*) Priestley *on Air,* vol. ii. p. 154. (*b.*) Scheele *on Air and Fire,* p. 43. (*c.*) *Phil. Trans.* 1803, p. 174. (*d.*) *An. Phil.* O.S. vol. vi. p. 340. (*e.*) *An. Phil.* O.S. vol. vii. p. 218. (*f.*) Thenard, *Syst.* vol. i. p. 273. (*g.*) Dulong and Petit, *An. de Ch. et Ph.* vol. x. (*h.*) Davy, *Phil. Trans.* 1817.

§ 2. *Chlorine.*

Chlorine.

(133.) A. It is now the prevailing opinion that Chlorine is a simple elementary body, and as such it will here be considered. The origin of this opinion must, with reference to our scheme of description, form the early History of this substance, and may be briefly stated as follows. Muriatic, or marine Acid, as it was first called, was known to Chemists. Scheele first obtained Chlorine from it in 1774, and called the new substance dephlogisticated marine Acid, consonant to his own doctrines respecting phlogiston. The French Chemists changed this name to that of oxygenized muriatic Acid, and this was again altered by contracting it to oxymuriatic Acid.

Chlorine has not been discovered in an uncombined form in Nature: it exists, however, in great abundance as a constituent of muriatic Acid, which again is neutralized by various alkaline substances. Thus, as muriate of soda, it exists in the waters of the ocean: and is also found in the solid form (common salt) in large deposits in various parts of the Earth.

(134.) B. Chlorine Gas is most readily obtained by putting two parts of strong muriatic Acid mixed with one part of the common black oxide of manganese into a glass retort and applying a gentle heat. The Gas is evolved in considerable quantity, and should be received in inverted bottles over the pneumatic trough. The water with which the trough is filled should be quite warm, and the bottles when filled should all be closed with glass-stoppers, to which a little lard has been applied. Want of space will, for the most part, prevent us from tracing the progress of most of the decompositions which the processes recommended in this Treatise may present: but such considerations are of first-rate importance to the Chemist, and as an example we shall here note the rationale of the above decomposition. Black oxide of manganese consists of one atom of metal + two atoms of oxygen. Muriatic Acid of one atom of Chlorine + one atom of hydrogen. In the mutual reaction of these substances, an atom of the oxide is decomposed, so that it is reduced to a lower state of oxidation; the atom of oxygen that is set free unites with the atom of hydrogen from the muriatic Acid so as to form water: the remaining atom of Chlorine is set free; the newly formed protoxide of manganese unites with an unaltered atom of muriatic Acid, and a proto-muriate of manganese remains in the retort.

For the purposes of the manufacturer a cheaper process is employed. Three parts of common salt are well mixed with one part of the black oxide of manganese, and then put into a retort. To this a mixture of four parts of diluted sulphuric Acid (containing 3-5ths acid and 2-5ths water) is added, and a moderate heat applied as before.

(135.) C. Chlorine Gas has a yellowish green colour, from whence its name is derived. (χλωρὸς.) It is violently irritative both to the nostrils and to the fauces, and highly disagreeable and injurious if even in small quantity it reaches the lungs. By violent condensation it evolves both light and heat. Under a pressure of four atmospheres it forms a bright yellow liquid, which does not freeze at zero, Fahrenheit. Its Specific Gravity is 2.5. (Thomson.) Cold water freed from common air by boiling will absorb and retain twice its volume of this Gas. When Chlorine Gas saturated with moisture is exposed to a cold of 32° Fahrenheit, yellow crystals are formed, containing, according to Mr. Faraday, a definite proportion of one atom of Chlorine + ten atoms of water.

(136.) D. Chlorine and oxygen when mixed together have no mutual action; but if either of the elements be present in a nascent state, by which is meant, at the instant of their disengagement from combination, a union may be effected.

In this manner four or five combinations with oxygen may be obtained. See subsects. 1, 2, 3, 4, and 5.

(137.) F. Unknown.

(138.) G. Chlorine unites with iodine, forming the chloriodic Acid. See sect. 4. subsect. 2 of this Chapter.

(139.) H. Chlorine unites with hydrogen, carbon, phosphorus, sulphur, selenion, and nitrogen. The compound with hydrogen is muriatic Acid, or as it is more properly termed, hydro-chloric Acid. See subsect. 6.

With carbon, Chlorine forms three combinations; the sub-chloride of carbon, the proto-chloride of carbon, and the hemideuto-chloride of carbon, called the perchloride, by Mr. Faraday, who discovered it. These compounds will be described in the section on carbon. Two chlorides of phosphorus exist, which will be described in sect. 5. So also for the chloride of sulphur, see sect. 6. For its union with selenion, see sect. 7. And for the chloride of nitrogen, (azotane,) see sect. 8.

(140.) I. The metals have in general a strong affinity for Chlorine; and it would seem that both true chlorides and chlorides of their oxides exist. In fact, every metal seems to be capable of uniting with Chlorine, and sometimes in more than one proportion. All these compounds are solid, with the exception of the deuto-chlorides of tin and arsenic, which are liquid and volatile. Many of the chlorides are crystalline powders. Generally speaking, the metallic chlorides are not decomposed by heat, but those of gold and platinum are so. The chlorides of the first two classes of metals are infusible below a red heat, and are not volatile. But those of the other metals are much more fusible, and frequently very volatile. All are soluble in water, excepting the chloride of silver and the proto-chloride of mercury: they for the most part absorb moisture with avidity. It appears, however, that in most cases their union with water is not a case of mere solution, but that a portion of the water is decomposed, so that its hydrogen unites with the Chlorine to form hydro-chloric Acid, while the oxygen goes to the metal, so as to produce a metallic oxide which, uniting with the hydro-chloric acid, produces a Salt. These phenomena are not, however, obvious in their progress, but it is very generally supposed that, in dissolving a metallic chloride, a solution of a hydro-chlorate is produced: and conversely, that in drying a hydro-chlorate sufficiently a metallic chloride is the result.

These generalizations, however, are not free from some exceptions, and some doubts which we have not space here to examine.

(141.) K. It is obvious that, strictly speaking, Chlorine has no action that can be referred to this division of our scheme.

(142.) L. The distinguishing properties of Chlorine are, that it has a greenish yellow colour: that it is unaltered by exposure to heat: that it immediately combines with mercury at ordinary temperatures: that it destroys vegetable colours. When present in a liquid, a white curdy precipitate is produced by nitrate of silver; which precipitate is insoluble in nitric Acid, but soluble in ammonia. A solution of the white of egg (*albumen*) produces a white floculent precipitate composed of flexible and elastic fibres, which are insoluble in water and alcohol.

(143.) M. The first and most important use of Chlorine in the Arts is in *Bleaching*, which will form a por-

f the applications of Chemistry to the Arts. This
s also the most powerful corrective or destroyer of
is miasmata. For this purpose it has long been
yed in lazarettos and hospitals. It forms the
ful ingredient in Labaracq's disinfecting liquor;
it is combined with lime or soda. This last pre-
on has only recently been introduced into this
ry, under the name above mentioned: and we
that, in cases of infectious disease, even in private
es, its use cannot be too strongly recommended.

Subsect. 1.—*Protoxide of Chlorine.*

4.) All the combinations between chlorine and
n are held together by a very feeble affinity, and
erefore, readily decomposed. Four are at present
, though from inadvertency two only are put
in our synoptic view. (4.) The atomic constitu-
f these, together with the circumstance just ad-
to, would lead us to suppose that some interme-
ombination may be found to exist whensoever our
may be found sufficiently delicate for their detec-
Indeed a fifth oxide is described by Count Von
n.
toxide of chlorine was discovered by Sir H.
in 1811, and was named by him *Euchlorine.*
ost readily obtained by placing two parts of the
e of potassa, one part of muriatic Acid, and one
er, in a small retort, and then applying a very
heat. The Gas evolved should be collected over
ry. A portion of chlorine is produced, but this
with the mercury, while the protoxide of chlorine
ected pure.
colour of this Gas is a yellowish green, but more
han that of chlorine. It has a smell something
at of burned sugar. Water will absorb eight or
es its volume of this Gas. Euchlorine does not
vith alkalis. Like chlorine it discharges vegeta-
lours, but with less energy than the latter sub-
It is so highly explosive, that the heat of the
s sufficient to produce a separation between its
uents. Phosphorus, also, immersed in it, produces
ion and undergoes combustion. When exploded
ydrogen by the electric spark, water and muriatic
re the results. Euchlorine consists of two vo-
of chlorine and one of oxygen. Its atomic con-
n and Specific Gravity will be seen in the gene-
bles. (*a.*)

Subsect. 2.—*Tritoxide of Chlorine.*

.) The tritoxide of chlorine was discovered and
ibed by Count Von Stadion in Gilbert's *Annalen.*
ome doubt, however, yet remains about this sub-

ect. 3.—*Tetartoxide of Chlorine.* (*Peroxide of Davy.*)

.) The *tetartoxide of chlorine* was discovered by
Davy in 1815, and also by Von Stadion about
e period. About 50 or 60 grains of the chlorate
ssa is reduced to fine powder, and formed into
with strong sulphuric Acid. This paste is to be
a glass retort, and then to be submitted to the
a water bath, not reaching so high as 212° of
ature. The Gas evolved is of a higher colour than chlorine or its protoxide, having an aromatic odour without any smell of chlorine. It does not combine with mercury, but is absorbed by water in considerable quantity. It does not combine with alkalis, but it destroys vegetable blue colours without previously reddening them, in which respect it differs from the protoxide. Phosphorus introduced into it produces decomposition and undergoes combustion. By the experiments of Davy and Gay Lussac, it appears that 40 volumes of the Gas become 60 after explosion; and are then found to consist of 40 volumes of oxygen and 20 of chlorine.

Part II.

Subsect. 4.—*Chloric Acid.* (*Pemptoxide of Chlorine.*)

(147.) *Chloric Acid* was first recognised as such in the chlorates, and pointed out by Mr. Chenevix. Its more careful examination was undertaken by M. Vauquelin (*d.*) and by M. Gay Lussac. (*e.*)

Vauquelin's process for obtaining it is as follows. To a solution of pure chlorate of baryta add, by degrees, diluted sulphuric Acid as long as any precipitation takes place. Thus the chloric Acid remains pure, combined with water only: care must of course be taken to add no more sulphuric Acid than is just sufficient to effect the separation of the baryta. The true point has been obtained when neither sulphuric Acid nor chlorate of baryta will produce a precipitate when added to separate portions of the Liquid.

The solution of chloric Acid thus obtained is colourless, having an acid or astringent taste. It reddens litmus: is volatilized by heat, but undergoes some decomposition in the process. It does not produce any precipitate from nitrates of silver, mercury, or lead. When chloric Acid and hydrochloric Acid are mixed together in just proportion, a complete decomposition is effected, chlorine and water resulting. It is decomposed by sulphuretted hydrogen or by sulphurous Acid, but none of the Acids which are saturated with oxygen have any action upon chloric Acid. It is also decomposed by all the metals which are capable of decomposing water, and chlorides of their oxides are produced. The constitution of chloric Acid is most generally supposed to be one atom chlorine + five atoms oxygen. (*f.*)

Subsect. 5.—*Perchloric Acid.* (*Heptoxide of Chlorine.*)

(148.) In obtaining the tetartoxide of chlorine by the process already given, (146.) a peculiar Salt was detected in the residuary matter by Count Von Stadion. It is found in octohedral crystals mixed with bisulphate of potash. These crystals are soluble in hot water, and also in 55 times their weight of water, at 60° Fahrenheit. It is insoluble in alcohol. By mixing this Salt with an equal quantity of sulphuric Acid, and distilling it at a temperature of 280° Fahrenheit, the salt is decomposed, and an Acid which has been called the perchloric may be distilled over. (*g.*)

Subsect. 6.—*Hydro-chloric Acid.* (*Muriatic Acid.*)

Hydro-chloric Acid.

(149.) A. Professor Thomson is of opinion that hydro-chloric Acid was known to the alchemists, and states that it is mentioned in the writings of Basil Valentine. Glauber, he says, seems to have contrived the present mode of obtaining it by distillation from sulphuric

Acid and common salt. Mr. Cavendish first described the mode of obtaining it in the Gaseous form, in 1766. (*k.*) Priestley more fully described its properties. (*i.*) The experiments of Gay Lussac and Thenard (*k.*) tended to prove that muriatic Acid Gas is a compound of chlorine and hydrogen: and the further researches and reasoning of Davy went far towards establishing the same opinion, which is in fact now almost universally admitted. (*l.*)

Muriatic Acid exists, as has been already stated, (133.) in great abundance in the earth and in sea water, combined with alkaline bases: but in the state of a free Acid it does not seem to exist at all, unless, possibly, it may be evolved among the Gaseous products of active volcanos.

(150.) B. Hydro-chloric Acid, as it is commonly known and made use of, is a Liquid, consisting of the pure Acid Gas combined with water. This Gas is most readily obtained by putting chloride of sodium, (common Salt,) well dried, into a tubulated retort, and then adding to it strong sulphuric Acid. By applying the heat of a sand-bath, muriatic Acid Gas is evolved in considerable quantity. If this operation be conducted over mercury the Gas is obtained in great purity, but not without a considerable degree of hygrometric water. If, however, the beak of the retort be made to terminate in a receiver containing water the Gas is absorbed, and a strong liquid solution of the Acid is obtained. But in purposely preparing the liquid muriatic Acid, it is most convenient to employ a series of two or three Woulfe's bottles, having a small quantity of water in each, so that whatever Gas may escape from solution in the first bottle, can only pass on and be taken up by the Liquid in the second or third. The proportions recommended for this process are as follows: dried chloride of sodium eight parts; strong sulphuric Acid seven parts; water placed in the Woulfe's bottles five or six parts. The proportions recommended by the College of Physicians is two pounds troy of dry chloride of sodium; 20 ounces troy of strong sulphuric Acid mixed with half a pint of water. A pint of water is to be put into the receiver to absorb the Gas. For a very clear view of the rationale of this process for obtaining muriatic Acid, see Mr. Phillip's excellent and scientific translation of the *Pharmacopœia.*

Hydro-chloric Acid Gas may also be formed by the direct synthesis of its constituents. Thus, if equal volumes of chlorine and hydrogen Gases be mixed together in a bottle, and kept from the influence of light, no change is produced; but by applying a lighted taper, or passing an electric spark through the mixture, or even by exposing it to the light of the sun, combination is instantly effected. Mr. Brande found that the intense light from charcoal points, ignited by the Voltaic pile, were capable of producing the same effect: (*m.*) and Seebeck states that, among different colours, the blue rays of the spectrum are more effectual than those which are red. (*n.*)

Hydro-chloric Acid Gas, for experiment, may also be obtained by heating a little strong muriatic Acid in a retort over a spirit-lamp. This Gas, when quite dry, consists of one atom chlorine + one atom hydrogen, or 36 of the former + one of the latter by weight.

(151.) C. In the Gaseous state, hydro-chloric Acid has the following Physical properties. Its smell and taste are extremely pungent, and it is quite unfit for respiration. It is heavier than common air; the best estimate of its Specific Gravity being 1.284366. (Thomson.) By heat alone it undergoes no change. Under a pressure of 40 atmospheres, and at a temperature of 50° Fahrenheit, it becomes a Liquid. It instantly extinguishes flame.

(152.) D. When oxygen and hydro-chloric Acid Gases are mixed together, and either passed through a red-hot porcelain tube or submitted to the electric spark, the chlorine is set free, and the oxygen unites with the hydrogen to form water. Dr. Henry states, that a similar decomposition is effected by inserting spongy platinum in the mixture at a temperature of 250° Fahrenheit.

(153.) E. No effect is to be expected under this head.

(154.) F. Unknown.

(155.) G. Iodine is slightly soluble in liquid hydrate of muriatic Acid, but with any action between the two substances in the Gaseous state we are not acquainted.

(156.) H. Muriatic Acid has no action on silicon, or its oxide silica. Neither has it upon hydrogen. Carbon is not soluble in it, but common charcoal will condense in its pores an enormous quantity of hydro-chloric Acid gas. We are not aware of any action between boron and this Acid. The same may be said of phosphorus, sulphur, selenion, and nitrogen.

Muriatic Acid possesses a very strong affinity for water: insomuch that it is extremely difficult to obtain it quite free from that substance. When a lump of ice is admitted to a jar of muriatic Acid Gas confined over mercury, the ice liquefies as rapidly as if it had been placed in a fire. According to Dr. Thomson, one cubic inch of water, temperature 69° Fahrenheit, will absorb 418 cubic inches of muriatic Acid Gas, producing an Acid the Specific Gravity of which is 1.1958. A useful Table has been given by Thomson, showing the quantity of real Acid in solutions of different Specific Gravities: it is calculated on the principle that, in forming a solution of marble in this Acid, every 50 grains dissolved indicate 37 grains of real Acid. See Part V. Table II.

(157.) I. As muriatic Acid is incapable of affording oxygen, it does not act energetically upon the metals: but by its determining power of affinity it induces many of the metals to decompose water when present, and thus to obtain oxygen. Such is the case with iron or zinc, when hydrogen is evolved. When potassium, tin, or zinc is heated in hydro-chloric Acid Gas over mercury, the Gas undergoes decomposition, a metallic chloride is formed, and hydrogen is set free.

(158.) K. With other Acids the hydro-chloric cannot be said to act as a base, though some mutual actions take place on their admixture: these are generally instances of decomposition dependent principally upon either the affinities of oxygen and hydrogen for each other, or upon that of chlorine for the radical of the other Acid employed. Thus it is decomposed by the nitric, chloric, iodic, chromic, and molybdic, so that it cannot exist with these in the same solution.

Hydro-chloric Acid exerts a strong affinity towards metallic oxides, and decomposes many of their combinations with other Acids. The muriates, or as we should more strictly call them, the hydro-chlorates, form a numerous and important class of Salts, which we shall have frequently to mention. All the true hydro-chlorates are neutral, and all contain water; for when, by great heat, this Liquid is driven off, they pass to the state of chlorides. All are decomposed by the sulphuric

Acid, even when cold, and still more easily by the aid of heat. With heat the muriates are decomposed by the phosphoric, arsenic, and boracic Acids, when water is present. The nitric Acid has the same property in proportion to its strength.

(159.) L. The hydro-chloric Acid is recognised in a solution by its property of producing a white curdy precipitate with nitrate of silver, a test of very great delicacy. The precipitate thus produced is the chloride of silver, which should be well washed, dried, and fused in a glass vessel. In this state it contains one atom of chlorine + one atom of silver, or 36 parts of the former + 110 of the latter by weight, indicating 37 parts by weight of dry muriatic Acid.

(160.) M. In the Arts hydro-chloric Acid is frequently employed as a solvent: and in Medicine it is given as a tonic. Dr. Prout made the singular discovery of its existence among the fluids of the stomach, sometimes in considerable quantity, in which case it seems to indicate a diseased action of that organ: and the mode of its production there appears extraordinary, since he could detect its presence in the stomachs of rabbits which had been fed on substances not apparently containing that Acid or its chief elementary constituent, chlorine. (*o.*)

(161.) We have adverted only slightly to the controversy that has existed between Chemists of first-rate excellence respecting the nature of chlorine and muriatic Acid. The one party having regarded chlorine as the simple elementary body, and muriatic Acid a compound formed by the addition of hydrogen: the other party having supposed muriatic Acid Gas the simple body, or at least that it consisted of an unknown radical united to oxygen; and that chlorine, or as it was by them termed, oxymuriatic Acid Gas, was a compound of oxygen with muriatic Acid Gas. The former, which is now the prevailing opinion, we have followed; but there is much in the controversial writings on this point that we strongly recommend to the attention of the Chemical reader, produced as they have been by the most distinguished Chemists of the Age. For this purpose consult reference. (*p.*)

References to § 2.

(*a.*) Davy, *Phil. Trans.* 1811. (*b.*) Von Stadion, Thoms. *An.* O.S. vol. ix. p. 22. from Gilbert's *Annalen*, vol. iii. p. 197. (*c.*) Davy, *Phil. Trans.* 1815, Part II. (*d*). Vauquelin, *An. de Ch.* vol. xcv. p. 102. (*e.*) Gay Lussac, *An. de Ch.* vol. xci. p. 111. (*f.*) *Ibid.* (*g.*) Von Stadion, *ut suprà.* Gay Lussac, *An. de Ch.* vol. ix. (*h.*) *Phil. Trans.* vol. lvi. p. 157. (*i.*) Priestley, *On Airs*, vol. ii. p. 276. (*k.*) *Mém. d'Arcueil*, vol. ii. p. 307, 320, 322. (*l.*) *Phil. Trans.* 1809. (*m.*) Brande, *Phil. Trans.* 1820. (*n.*) Seebeck, Nich. *Jour.* vol. xxxiv. p. 220. (*o.*) Prout, *Phil. Trans.* 1824, p. 45. (*p.*) *Memoirs* by Dr. Murray and J. Davy, Nich. *Jour.* vol. xxxiv. Sir H. Davy, *Phil. Trans.* 1818, p. 169. *Trans. R. S. Edin.* vol. viii. *An. Phil.* O. S. vol. xii. p. 379. and vol. xiii. pp. 26, 285. Phillip, *An. Phil.* N. S. vol. i. p. 27.

§ 3.—*Fluorine.*

(162.) In assigning to Fluorine its present situation in our system, we acknowledge that we are acting upon supposition, and not upon fact. We are aware that in so doing we shall find the opinions of some very distinguished Chemists opposed to us: but after all, in a matter confessedly undecided, we are willing to shelter ourselves from absolute censure, by saying that we only adopt the opinions of Sir H. Davy, advocated by Dr. Thomson, and perhaps by Berzelius also. On the whole, it seems to us the more plausible of the two generally proposed. It may be well just briefly to state that the one of these suppositions is, that Fluorine is a highly electronegative body, (analogous to chlorine,) and that by its union with hydrogen Fluoric Acid is formed, which should, therefore, be called hydro-fluoric Acid. On the other supposition Fluorine is a base, (analogous to boron,) and that Fluoric Acid arises from the union of this base with oxygen.

(163.) A. Fluorine is so far from existing at all free in any part of the kingdom of Nature, that it has never yet been exhibited alone and uncombined by the utmost efforts of Chemical ingenuity. Fluoric Acid had long been suspected to be a compound of some unknown base with oxygen: but in 1810, M. Ampere was led by the analogy of chlorine to view it in the light of a compound of that base with hydrogen. This he communicated to Sir H. Davy, who published in 1813 and 1814 two very valuable papers in support of that opinion. To these papers we are indebted for the little that we know concerning the base of Fluoric Acid.

(164.) B. Sir H. Davy did not obtain Fluorine in a separate state, but the following were the modes by which he attempted to do so; together with the evidence which he obtained in favour of Ampere's and his own opinion. Potassium was added to Fluoric Acid, a violent degree of action ensued, hydrogen Gas was evolved, and a solid white residuum was obtained. Now, if it were certain that Fluoric Acid contained no water, we must infer that the Fluoric Acid underwent decomposition by the escape of its hydrogen, and that the white mass was a Fluoride of potassium. To ascertain whether the strong liquid Fluoric Acid (Specific Gravity 1.0609) contained water, Davy enclosed some in a platinum capsule within dry ammoniacal Gas, until it became saturated with that alkali. Thus dry Fluate of ammonia was obtained. According to the belief of Davy and Thomson, "when any Acid that contains water is combined in this manner with ammoniacal Gas, if we heat the Salt formed, water is always disengaged. Thus sulphuric, or nitric, or phosphoric Acid, when saturated with ammoniacal Gas and heated, give out always abundance of water." (Thomson.) Fluate of ammonia thus treated gave out no water. (*a.*) Upon this ground it seemed that Fluoric Acid contained no water.

The analogy with muriatic Acid seems plausible also By heating potassium with muriate of ammonia, the Salt and its Acid are both decomposed. Chloride of potassium is formed, and the hydrogen and ammonia both escape, in the proportion of one volume of the former to two of the latter. So also if Fluate of ammonia be heated with potassium, a mixture of hydrogen and ammonia escapes containing precisely the same proportions as in the former case, and a solid white residuum is found and by analogy inferred to be the fluoride of potassium. (*b.*)

Again, by exposing Fluoric Acid to the Galvanic pile: hydrogen was evolved at the negative wire, and the opposite wire, which was of platinum, was coated with a chocolate-coloured powder. (*c.*) When muriatic Acid is similarly acted upon, hydrogen is given out at the negative wire, and a chloride is formed round the extremity of the positive wire. Reasoning upon this analogy, the chocolate powder would seem to be a Fluoride of platinum.

When Fluate of silver or fluate of mercury is exposed to the action of chlorine, and heated in a glass vessel, a metallic chloride is formed, the glass is corroded, and a quantity of Gas evolved, which is found to consist of oxygen and silicated Fluoric Acid Gas. In this case it is supposed "that the Fluorine is disengaged, that it immediately acts upon the silica in the glass, disengaging its oxygen and forming silicated Fluoric Acid, which may be considered as a compound of Fluorine and silicon." (Thomson.)

Such are the views of the able Chemist whose name has just occurred, in illustration of Davy's hypothesis. They seem to have much weight: but it may be fair to add that their accuracy has been questioned by other writers on this subject.

The attempts made by Davy to obtain fluorine separately, by repeating the last-mentioned experiment in silver or platinum vessels instead of glass, were always rendered unsuccessful by the Fluorine entering into combination with those metals respectively.

(165.) C. D. E. G. None, or unknown.

(166.) H. Of the substances under this head, the compounds of hydrogen, boron, and silicon, with Fluorine, are all that have yet been examined. These, as they form peculiar Acids, will form three subsections to be noticed shortly.

(167.) I. We have already seen that Fluorine unites energetically with potassium, and also with platinum and silver; and may consider it probable that it will do so with every other metal. Those who entirely adopt Davy's views of Fluorine, will consider Fluor spar (or Fluate of lime, as it must be on the opposite creed) as a true Fluoride of calcium. Suppose a piece of this well-known and beautiful mineral to be acted upon by sulphuric Acid, which with the aid of heat is capable of effecting its decomposition. The water also of the sulphuric Acid is decomposed, its hydrogen unites with the fluorine to form hydro-fluoric Acid, which is one product, and its oxygen unites with the calcium to form the base of sulphate of lime, the other product.

(168.) K. L. M. Unknown.

Subsect. 1.—*Hydro-fluoric Acid.*

Hydro-fluoric Acid.

(169.) A. Hydro-fluoric Acid has been long known by the name of fluoric Acid. The following is Thomson's summary of its history.

"Fluor spar, a well-known mineral, is mentioned by Agricola under the name of fluor as a flux for metallic ores. (*e.*) Its property of corroding glass when mixed with sulphuric Acid was known at Nuremberg as early as 1670. The first attempt to ascertain the composition of this mineral was made by Margraaf. His experiments were published in the *Memoirs of the Berlin Academy* for 1768, but he informs us that they had been made in 1674. He reduced the mineral to powder, mixed it with its own weight of sulphuric Acid, and distilled it in a retort. He obtained a white, saline sublimate, and remarked with surprise that the retort was corroded into holes in several places. (*f.*) In the year 1771 Scheele published a set of experiments on fluor spar, in the *Memoirs of the Academy of Sciences of Stockholm.* He showed that the mineral was a compound of lime and of a peculiar Acid, to which he gave the name of fluoric Acid. He determined the properties of this Acid, and showed it to differ from every other previously known. (*g.*) Dr. Priestley found that the Acids when obtained by Scheele's process, is a Gas possessed of peculiar properties, which he investigated and described. (*h.*)

"It was shown by Weiglib (*i.*) and Bucholz, (*k*) and still more completely by Meyer, (*l.*) that the fluoric Acid of Scheele contained silica as a constituent; and Dr. John Davy ascertained the proportion of fluoric Acid and of silica that exist in the Acid of Scheele, and demonstrated that it is a peculiar compound of fluoric Acid and silica, in which the constituents always exist in the same proportions. (*m.*) Gay Lussac and Thenard, in 1811, published a method of preparing pure fluoric Acid, and were the first to determine its properties."(*n.*) Four fluates exist in Nature; the one already mentioned, fluate of cerium, double fluate of cerium and yttria, and the double fluate of soda and alumina, cryolite.

(170.) B. The method of Gay Lussac and Thenard is generally adopted. A retort and receiver of lead are made to fit well together. Into the retort put a quantity of pure fluor spar in fine powder, together with twice its weight of sulphuric Acid. Lute the apparatus, and apply a gentle heat to the retort; at the same time surrounding the receiver with a freezing mixture of snow and salt. The fluoric Acid is condensed in the receiver in the liquid form.

(171.) C. "At 32° Fahrenheit it is a colourless Liquid, like water. It does not congeal though cooled down to —4° Fahrenheit, and it remains a Liquid at 60° Fahrenheit. Its boiling point has not been determined, but it is low. When exposed to the air, it smokes violently, giving out a smell similar to that of muriatic Acid, but much stronger. It is very speedily dissipated in open vessels, and can only be preserved in metallic ones. The best are those formed of pure silver, and they must have a silver stopper which should be air-tight." (Thomson.)

This Acid, as obtained by Davy at its utmost concentration, was of Specific Gravity 1.0609. In this state he considered it quite free from water. If a drop of the Acid be let fall into water it combines with a hissing noise, like that which would be produced by red-hot iron; but when a few drops of water are poured into fluoric Acid ebullition is produced.

Fluoric Acid acts powerfully upon the animal system, the least drop acting as an escharotic, and producing a sore which is healed with difficulty. The fumes of it are repelled by the lungs with violence, and are so deleterious that scarcely the smallest portion can enter those organs with impunity.

(172.) D. The action of hydro-fluoric Acid upon the metals has been already noticed (163.) in connection with what we conceive to be the decomposition of this Acid to obtain fluorine. Its union with potassium and sodium, as examined by Thenard and Gay Lussac, is extremely violent, great heat, with effervescence, and the evolution of hydrogen, all resulting. Thenard states, also, that they tried three other metals, zinc, iron, and manganese. All three decompose the hydro-fluoric Acid with the evolution of heat and hydrogen Gas. M. Thenard considers it scarcely probable that any other metals, except those of his first two sections, and perhaps tin and cadmium, would produce any action upon this Acid. We have already stated our belief that fluorine will unite with every metal, but this is not opposed to M. Thenard's opinion, because it does not thence follow that every metal will decompose the hydro-fluoric Acid for the purpose of uniting with its base, without some other determining agency; such, for instance, is Voltaic electricity.

(173.) E. Thenard states that the non-metallic combustibles, both simple and compound, have no action upon hydro-fluoric Acid.

(174.) E. and F. none.

(175.) G. none, or unknown.

(176.) I. none, or unknown.

(177.) K. With regard to the compounds formed by hydro-fluoric Acid with salifiable bases, we shall abridge the following general notice from Thenard's system.

The hydro-fluate of ammonia is obtained by adding a dilute solution of ammonia to hydro-fluoric Acid, until the alkali be slightly in excess, and then evaporating by a gentle heat.

Of the metallic hydro-fluates there are twenty-one single ones already described, besides some double ones. Of these twenty-one, fifteen belong to the first three sections, and the six others are those of cobalt, copper, silver, lead, and mercury.

All these hydro-fluates are fusible by heat, provided they do not undergo decomposition. None of these Salts, if perfectly dry, could be decomposed by fire; but if humid, it is possible that many of them might undergo partial or total decomposition, because water has a strong affinity for hydro-fluoric Acid, and consequently in disengaging itself it might either wholly or in part carry off the Acid along with it. This effect is never produced upon the neutral hydro-fluates of the second section, nor on those of magnesia, silver, zinc, and iron; but it does take place with those of lead, cobalt, and copper, and they become reduced to the state of subhydro-fluates.

With regard to the action of the simple combustibles upon the hydro-fluates, much might be said, which entirely depends upon the theoretical view taken of the elementary body we are now describing. The relation existing between boron and this base has already been noticed; and it seems probable that combinations with other substances of this class may yet be discovered.

(178.) Water dissolves none of the metallic hydro-fluates at present known when in the neutral state; except those of potash, soda, and silver. But all are soluble in an excess of Acid.

(179.) The salifiable bases seem to unite with hydro-fluoric Acid through the medium of water in this order: lime, barytes, strontian, potash, soda, ammonia, magnesia, &c.

(180.) "The boracic Acid is the only one which is capable of decomposing the hydro-fluates *per se*, without the aid of water. If a mixture of two parts of fluor spar and one part of boracic Acid be heated nearly to redness in a bent gun-barrel, we obtain a residuum of hydro-fluate of lime and boro-fluoric (fluo-boric) Acid Gas. On the other hand, there are many Acids capable of decomposing the hydro-fluates through the medium of water; such are the sulphuric, the phosphoric, the arsenic. When a concentrated solution of these Acids is heated with a hydro-fluate in a leaden or silver vessel, there results a fixed sulphate, phosphate, or arseniate; and a compound of hydro-fluoric Acid and water, which is disengaged with effervescence, and disperses white pungent vapours through the atmosphere. Sulphuric Acid can even decompose many of these Salts at our ordinary atmospheric temperature. Many also are decomposed by the nitric, hydro-chloric, hydriodic, and especially by the hydro-sulphuric; but in no case by the sulphurous, nitrous, or carbonic Acids."

(181.) Silica has, like water, the property of facilitating the decomposition of the hydro-fluates. For example, if pure fluor spar be calcined with acid phosphate of lime in an iron tube, the vitreous Acid phosphate of lime does not decompose the fluor at the highest temperature. But if pure dry silica or sand be added, the decomposition takes place at a low red heat; and phosphate of lime, with a great quantity of silico-fluoric Acid Gas, are the results. From this experiment Thenard infers, that most of the hydro-fluates of the last four sections, which are not decomposable by charcoal at any temperature when dry, might easily be decomposed by that body, if a quantity of silica were added to the mixture. Or even it is probable that this might be effected by silica alone; for, on the one hand, it would tend to unite with the metallic oxide, and on the other hand, with the hydro-fluoric Acid; and, indeed, it is not impossible that many fluates of the first two sections may be similarly affected, especially at very elevated temperatures.

(182.) If a solution of hydro-fluate of ammonia, potash, or soda, be added to a solution of a Salt of barytes, strontian, lime, magnesia, alumina, zinc, iron, lead, mercury, &c. the insoluble hydro-fluates of these bases are precipitated; at least if the solution be nearly neutral. But the soluble salts of glycina, yttria, and zirconia present some singularities. In fact, by adding a solution of hydro-fluate of potash slightly acid to a solution of the hydro-chlorate of each of these salts, all being slightly acid, we obtain on the one hand a precipitate of the neutral insoluble hydro-fluates, and on the other, the soluble hydro-chlorate of potash sensibly alkaline. (*o*.)

(183.) L. On this point we have little to add to that information which may be collected from the last article. The presence of hydro-fluoric Acid in a compound is usually recognised by decomposing that compound with sulphuric Acid, and allowing the escaping Gas to corrode glass. Berzelius has given modes for recognising it in mineral bodies in his *Essai de l'Employ du Chalumeau*, p. 159.

(184.) M. The only use to which the hydro-fluoric Acid has been applied is in the etching upon glass. This process is not difficult, and is sometimes very useful. Coat the glass with a thin but uniform layer of bees'-wax, then write or scrape off the parts that are to be etched with some sharp instrument, so as to leave the surface of the glass quite exposed. Then mix some well-pounded fluor spar with sulphuric Acid in a leaden or platinum crucible, and expose it to a moderate lamp heat. The hydro-fluoric Acid Gas will escape in white fumes, and eat into the exposed surface of the glass. The wax may then be removed by heat and an indelible writing or etching is found upon the glass.

Subsect. 2.—*Silico-fluoric Acid.*

Silico-fluoric Acid.

(185.) By this term we mean the silicated fluoric Gas of Scheele, fluo-silicic Acid of Thomson, and fluate of silica of Thenard. It may be said that, as we adopt Davy's and Thomson's opinions on the nature of this Acid, we ought to adopt Thomson's name for it. We by no means claim the right of introducing new names, a process ever replete with confusion; but if the compound of hydrogen with fluorine be called hydro-fluoric

Acid, so also should the compounds of silicon and boron, being also Acids, be called silico-fluoric and boro-fluoric Acids. Witness also hydro-chloric Acid, hydriocid acid, hydro-sulphurous Acid, &c.

(186.) A. We now return to the acid compound of silicon and fluorine mentioned Art. (163.) a Gaseous body which does not exist naturally in its simple form. It was discovered by Scheele. (*p.*) Priestley examined it further; (*q.*) and Dr. John Davy published a paper on it in 1812. (*r.*)

(187.) B. To obtain this Gas, let equal quantities of fluor spar and glass, both in fine powder, be just formed into a paste with sulphuric Acid. This paste is to be exposed to a moderate lamp-heat in a small retort, which in this case may be of glass. The silico-fluoric Acid Gas will be evolved in considerable quantity, and may be collected over the mercurial trough.

Silico-fluoric Acid consists of

1 proportion silicon. .	1.00	Thomson.
1 proportion fluorine	2.25	
	3.25	

(188.) C. This Gas is colourless, has a smell much like that of muriatic Acid, has an acid taste, and reddens vegetable blues. It produces white fumes on mixing with atmospheric air. It does not support combustion, nor must any quantity, however small, be suffered to enter the lungs. Its Specific Gravity, according to Dr. Davy, is 3.5735, or 3.6111 according to Thomson. Water absorbs this Gas in great quantity, but at the same time the Gas suffers decomposition, and part of the silica is deposited. Heat alone is not capable of decomposing this Gas.

(189.) D, E, F, G. Unknown.

(190.) H. No substance from this class of bodies will decompose silico-fluoric Acid even with the aid of heat.

(191.) I. The metals of the last four sections have no action on this Acid at any temperature. But if potassium or sodium be placed in this Gas, and then heated, a violent action takes place, the Gas is absorbed, all metallic appearance is lost, and a chocolate-brown substance remains. When this substance is put into water there is a slight effervescence, hydrogen escapes, and hydro-fluates of silica and of potash or soda are formed.

(192.) K. Silico-fluoric Acid Gas unites with twice its volume of Gaseous ammonia, and forms a Salt which is volatile below a red heat, and from which water can separate some part of its silica; but if placed in contact with liquid ammonia, the whole of the silica separates, and hydro-fluate of ammonia is formed.

The silico-fluates of potash, soda, lime, and barytes, are formed by adding a solution of silico-fluoric Acid Gas in water to the solutions of these bases respectively; but it must be remembered that, in all these compounds, the silica exists in a smaller proportion than in the original Gas, as some portion of that earth will separate whenever the gas enters into union with water.

(193.) L. Nothing can be said on this point in addition to what is obvious from the properties already noticed.

(194.) M. None.

Subsect 3.—Boro-fluoric Acid.

Boro-fluoric Acid.

(195.) A. Gay Lussac and Thenard first discovered that boron united with fluorine to form a powerfully acid Gas. (*s.*)

(196.) B. The process for obtaining this Gas, recommended by Dr. J. Davy, is to mix fused boracic Acid in fine powder one part; fluor spar in powder two parts; and sulphuric Acid twelve parts. This compound is to be gently heated over a lamp, and the Gas collected over mercury; or by exposing mixture of boracic Acid and fluor spar in fine powder to a red heat in a gun-barrel. (*t.*)

(197.) C. Boro-fluoric Acid Gas thus obtained is colourless, has the smell of hydro-chloric Acid, reddens vegetable blues, and has an acid taste. Dr. Davy states, that water will absorb 700 times its volume of this Gas; it then becomes a highly Acid Liquid, capable of forming an ether when distilled with alcohol. It has no action upon glass; instantly carbonizes animal and vegetable substances; is not decomposed by a red heat.

(198.) D. When this Gas is mixed with oxygen no decomposition is produced; but it seizes with avidity any moisture that may be present, and thus forms white fumes of vapour. The same takes place with all other gases.

(199.) E. As with oxygen.

(200.) F. Unexamined.

(201.) G. Unexamined.

(202.) H. No simple composition has any action on this Gas.

(203.) I. Among the metals, those of the third, fourth, fifth and sixth classes will not decompose boro-fluoric Acid Gas. Its decomposition has, however, been effected by potassium and sodium. These metals, when heated in the Gas, burn almost as in oxygen; boron and fluoride of potassium or sodium result from that decomposition. When water is added, an alkaline hydro-fluate is formed in solution, and boron remains.

(204.) K. The combination of this Gas with ammonia is the only Salt of this Acid that has been examined. Of the boro-fluate of ammonia there exist three varieties; the first a solid opake Salt; the second and third both are Liquids, though they contain no water: by exposure to the air they part with ammonia, and pass into the first variety. (*t.*)

(205.) L. The only application of this substance which has been suggested, is as a reagent, to detect moisture in other Gases, which it readily does, by the white fume formed when even only a very small portion of aqueous vapour is present.

(206.) M. None.

References to § 3.

(*a.*) Davy, ***Philosophical Transactions***, 1813, p. 268. (*b.*) *Ibid.* p. 269. (*c.*) *Ibid.* p. 271. (*d.*) *Ibid.* p. 275. (*e.*) *Geo. Agricola*, p. 458, Ed. Basil, 1558. (*f.*) *Collection Académique*, vol. xvi. p. 281. (*g.*) *Mémoires de Chymie de* Scheele, vol. i. p. 1. (*h.*) Priestley, *On Air*, vol. ii. p. 339. (*i.*) *Neues Entdeck. in der Chemie Th.* vol. i. p. 1—15. (*k.*) *Ut suprà*, ref. (*e.*) (*l.*) *Schriften der Berliner Gesellsch. Naturf. Fr.*, vol. ii. (*m.*) *Philosophical Transactions*, 1812, p. 352. (*n.*) *Recherches Physico-Chemiques*, vol. ii. p. 1, &c. (*o.*) Gay Lussac and Thenard, *Recherches Physico-Chemiques*, vol. ii. p. 27. (*p.*) Scheele, *Mém. de Ch.* vol. i. p. 24. (*q.*) Priestley, *On Air*, vol. ii. p. 339. (*r.*) J. Davy, *Philosophical Transactions*, 1812, p. 352. (*s.*) Gay Lussac and Thenard, *Mém. d'Arcueil*, vol. ii. p. 317, and *Recherches*,

vol. ii. p. 37. (*t.*) J. Davy, *Philosophical Transactions*, 1812, p. 365.

§ 4.—*Iodine.*

(207.) A. The discovery of Iodine resulted from an examination made by M. Courtois, a saltpetre-manufacturer at Paris, into the cause of the corrosion which took place upon the metallic vessels in which he separated soda from the ashes of sea-weeds. It was in 1812 that he thus detected this curious body and submitted it to MM. Clement and Desormes for further examination. The more complete inquiries into its nature were, however, made by M. Gay Lussac and Sir H. Davy, about the same time, *viz.* in 1813. The name Iodine was derived by M. Gay Lussac from *ιωδης*, *violaceus:* a property belonging to it in the Gaseous state. There seems to be considerable variation in the quantities of Iodine produced from different species of sea-weed, obtained from different places. Dr. Fyfe has published an examination of several of these, from which he obtained Iodine by adding sulphuric Acid to very concentrated infusions of the *Algæ*, (genus *Fucus*,) made by macerating them in hot water. (*a.*)

(208.) B. The marine plants that we have mentioned are collected in large quantities, and burned in heaps on the sea-shore. The ashes are collected and sold under the name of kelp to the soap-manufacturers for the sake of the soda that they contain. It is from this kelp that Iodine is most readily obtained. The process for which we are indebted to Dr. Wollaston is much the most commodious. The soluble part of the kelp is to be dissolved in water: evaporate the liquor so as to separate all the crystals that can be obtained. Pour off the remaining Liquid into a clear vessel, and add to it an excess of sulphuric Acid. By boiling this Liquid for some time sulphur is precipitated and hydrochloric Acid is driven off. Decant the clear liquor and strain it through wool. Then put it into a small flask, and mix with it as much black oxide of manganese as of sulphuric Acid used before. Apply to the top of the flask a glass tube, closed at one end. Then heat the mixture in the flask. The Iodine sublimes into the glass tube.

Dr. Ure obtained Iodine in considerable quantity from the waste ley which had been employed in making soap from Scotch kelp. (*b.*)

(209.) C. Iodine thus obtained is considered a simple body. It is solid at our ordinary temperatures. It is generally seen in small imperfect crystals of a lamellar structure; is of very slight tenacity; is of a blackish blue colour, with some metallic lustre; and has a good deal the appearance of a granular plumbago, or native sulphuret of antimony. By careful sublimation it is readily obtained in crystals, the primary form of which has been determined by Dr. Wollaston to be an octohedron, whose axes are nearly in the ratio of 2 : 3 : 4. (*c.*) Its Specific Gravity is 4.948 at temperature 62°.5 Fahrenheit, (*d.*) according to Thenard, but only 3.0844 according to Thomson. The taste of Iodine is acrid and hot, and its effects are poisonous. Its smell is like that of chlorine or chloride of sulphur. It is slightly volatile at even ordinary atmospheric temperatures: it fuses at 226° Fahrenheit, and boils at 347° Fahrenheit, but the colour of its vapour may be rendered obvious even at 100° Fahrenheit; and it entirely assumes the form of a beautiful violet coloured Gas much below 212° Fahrenheit, under the common atmospheric pressure. It is not a conductor of Electricity, for if a small fragment be placed between wires, so as to form a part of the Voltaic circuit, the decomposition of water does not take place. Iodine is soluble in 7000 times its weight of water, but it is much more soluble in alcohol, and still more so in ether.

(210.) D. The union of oxygen with Iodine may be effected indirectly: and thus a peculiar proximate element is formed, the *Iodic Acid*. See subsect. 1. Iodine is, in fact, capable of expelling oxygen from both sulphur and phosphorus. Professor Sementini of Naples has discovered another compound of oxygen and Iodine which he calls Iodous Acid, but as yet its properties are little known. (*o.*)

(211.) E. Sir H. Davy formed the combination between Iodine and chlorine at Florence in 1814, and thus discovered *Chloriodic Acid*. See subsect. 2.

(212.) F. The direct union between Iodine and fluorine is of course yet unknown, but M. Gay Lussac examined the action between fluate of potash (or fluoride of potassium) and Iodine: he says, "Sulphate of potash was not altered by Iodine, but what may appear astonishing, I obtained oxygen with the fluate of potash, (fluoride of potassium,) and the glass tube in which the operation was conducted underwent corrosion. On examining the circumstances of the experiment, I ascertained that the fluate became alkaline when melted in a platinum crucible. This happened to the fluate over which I passed Iodine. It appears then that the Iodine acts upon the excess of alkali and decomposes it. The heat produced disengages a new portion of fluoric Acid or its radical, which corrodes the glass; and thus, by degrees, the fluate is entirely decomposed."

(213.) H. Of the substances belonging to this division Iodine combines with hydrogen, phosphorus, sulphur, and azote. The affinity of Iodine for hydrogen is very considerable. It decomposes many substances in order to obtain it, and by the aid of heat, it is capable of absorbing a considerable quantity of this Gas. Thus is formed a peculiar Acid, the *Hydriodic*, to be described in subsect. 3.

(214.) Iodine and phosphorus unite when gently heated together in a glass tube over charcoal. The formation of Iodide of phosphorus takes place with increase of heat, but without the evolution of light. (*d.* p. 9.)

(215.) Sulphur unites with Iodine readily, but not with energetic action. Iodide of sulphur may be formed by combining the substances at a moderate heat; which heat, if again increased, readily produces their separation, and Iodine vapour escapes.

Iodine and carbon have not yet been united, nor have we any information respecting the action of Iodine with boron or selenion.

(216.) The compound of Iodine with azote was first formed by M. Courtois, by simply putting a quantity of Iodine into a solution of ammonia in water. A process of decomposition takes place, ammonia is decomposed, and the new compounds resulting are iodide of azote and hydriodate of ammonia. The latter remains in solution; the former falls down in the form of a black powder. In a quarter of an hour the process is complete and the Iodide may be washed upon a filter. This substance possesses violent detonating properties: when quite dry it will explode spontaneously; and when moist it will do so with only a very slight pressure.

When this detonation is made in close vessels, azote and Iodine are found to be the sole products. (*h.*) (*i.*)

(217.) I. "Though as yet Iodine has been united only to potassium, sodium, zinc, iron, tin, antimony, bismuth, copper, lead, mercury, and silver, yet it appears that this substance possesses, like chlorine, the property of combining with all the metals. It is also certain that the Iodides are subject to the same law of composition with the chlorides and the sulphurets; for first, when they are placed in water they decompose it, and possess themselves of its two constituent elements, thus transforming themselves into hydriodates. 2. If we calcine the hydriodates of the protoxides of potassium, sodium, &c. the result is water and Iodides. 3. When the hydriodic Acid is placed in contact with oxides, and it decomposes them, there also result Iodides and water. The quantity of Iodine in the Iodides is therefore proportional to the quantity of oxygen in the oxides.

"All the Iodides at present known are solid, brittle, and scentless: the greater part have some flavour, and the greater part also crystallize: many are without colour. Among those that are coloured, many have a very deep tint. The Iodide of lead is a vivid yellow; the protiodide of mercury is a beautiful yellow; and the deutiodide is a vermilion red.

"Some Iodides are volatile: such as those of potassium, sodium, zinc, and mercury.

"All, excepting those of potassium, sodium, lead, and bismuth, are decomposed by oxygen at a red heat. Iodine is disengaged in violet vapours and the metal is oxidated. Some, like the Iodide of zinc, deliquesce by exposure to the air.

"When placed in contact with water, the Iodides of potassium, sodium, zinc, and iron decompose it instantly, and dissolve therein, passing to the state of hydriodates. It is probable that the same takes place with the remaining Iodides of the two first classes of metals.

"The Iodides of tin and antimony also effect, at common temperatures, the decomposition of water; but the hydriodic Acid does not unite to the metallic oxides: these are precipitated, while the Acid remains in the liquid.

"Those of bismuth, copper, lead, mercury, silver, and, in general, almost all those formed of metals which do not decompose water, are, on the contrary, inert when placed in it, and are not dissolved.

"Iodine is expelled from its combinations with metals by chlorine at a high temperature: but at such a temperature it has almost always an affinity for the metals superior to that of sulphur and phosphorus.

"Lastly, there is no Iodide known, wherein the concentrated sulphuric or nitric Acids cannot oxidate the metal and disengage the Iodine." (*e.* Art. 248.)

(218.) L. The mutual action between starch and Iodine is very striking. Stromeyer asserts that a solution containing only 1 – 450000th part of Iodine produces a blue colour when mixed with a solution of starch. (*f.*) This colour varies from a delicate blue to a deep black, in proportion to the quantity of Iodine present. To ascertain whether a vegetable root contains starch, the root is cut transversely, and a drop of alcoholic solution of Iodine is let fall upon the cut surface; if the root contains any of that fæcula of which starch consists, the drop exhibits a blue tint. Should the Iodine exist in a state of combination, it is necessary to add a few drops of sulphuric Acid to disengage it, previous to the application of the test. With this reagent the presence of starch may be recognised in the solutions of some gums but not in those of others. By the help of this substance metallic palladium may be distinguished from metallic platinum. A drop of the tincture of Iodine is placed upon the polished surface and suffered to remain there. A black spot will be found upon both metals, but that upon platinum may be removed by heating the metal while that on palladium cannot.

(219.) M. Several preparations of Iodine have been recently introduced into Medical practice, for although this substance is an active poison, yet, as in many such cases, it may be exhibited in very small quantities: and the general opinion seems to be that it will form a valuable addition to the *Materia Medica.* On this head we can only direct our readers to M. Majendie's interesting Work. (*g.*) The most striking effects seem to have consisted in the dispersion of the goitre; and for this purpose it is now much employed in Swisserland.

Subsect. 1.—*Iodic Acid. Oxiodic Acid of Davy.*

(220.) A. This Acid is said to have been first recognised by M. Gay Lussac, but it was first obtained in a pure state by Sir H. Davy. It is entirely an artificial product, not having been found in Nature either in a simple or combined form.

(221.) B. To obtain Iodic Acid:—"Put 40 grains of Iodine into a thin, long-necked receiver. Into a bent glass tube, shut at one end, put 100 grains of chlorate of potash, and pour upon it 400 grains of hydrochloric Acid, of Specific Gravity 1.105: then make the bent tube communicate with the receiver and apply a gentle heat. Protoxide of chlorine is generated, which should be made to pass through dry chloride of calcium, in order to separate moisture. As soon as it meets with the Iodine two new compounds are formed: 1st, a compound of Iodine and chlorine—chloriodic Acid: and, 2dly, a compound of oxygen and iodine—oxiodic Acid. When heat is applied to this mixture, the chloriodic Acid, which is volatile, flies off, and the oxiodic Acid is left pure." (*k.*)

(222.) C. In this state it is a white semitransparent solid, without smell, but having a strongly acid flavour. In Specific Gravity it exceeds sulphuric Acid, as it will sink in that fluid. It first reddens and then destroys the colour of vegetable blues. It attracts moisture from the air slightly, and is very soluble in water. Such a solution gradually thickens by evaporation; then becomes pasty, and ends by remaining pure Iodic Acid. By a heat rather below the boiling temperature of olive oil it is decomposed into oxygen Gas and Iodine vapour. (*d.* p. 75.) and (*k.*)

(223.) D. E. F. G. unimportant or unexamined.

(224.) H. The combustible bodies exert a powerful action on Iodic Acid: for when it is heated with carbon, sulphur, resins, or sugar, a sudden detonation takes place.

(225.) I. The same effects are produced by many of the metals when they are in a state of minute division.

(226.) K. Iodic Acid unites with the sulphuric, phosphoric, nitric, and boracic Acids, forming crystalline compounds with the three first. It is decomposed by

phurous, phosphorous, hydriodic and hydro-sul-
s Acids.
n example of one these compounds: let sulphuric
e added drop by drop to a cold concentrated
n of Iodic Acid. A precipitate immediately takes
of *Iodo-sulphuric Acid.* This compound fuses
xposed to a gentle heat, and crystallizes, on
, in rhomboids of a pale yellow colour. By a
owerful heat, it is partly sublimed unchanged,
rtly decomposed into oxygen, iodine, and sulphu-
ls. These compound Acids have such energy in
tion upon metals as to dissolve even platinum.
dic and hydro-chloric Acids mutually decompose
her; producing water and chloriodic Acid.
the salifiable bases Iodic Acid forms Salts: and
hen neutral are in general of very slight solu-
So great is its affinity for the oxides of lead and
, that it precipitates them both from their solu-
nitric Acid. The iodates of ammonia, soda,
lime, barytes, strontia, zinc, and silver have been
ed. (*n.*)
) L. See (215.)
) M. None at present known.

Subsect. 2.—*Chloriodic Acid.*

) A. This substance, which is entirely an arti-
oduction, was discovered about the same time
Sir H. Davy and M. Gay Lussac.
) B. Chloriodic Acid is formed by passing a
of chlorine Gas into a vessel containing iodine.
ine absorbs the Gas and a yellow substance re-
hich by being fused with a gentle heat assumes
ge colour; but is red if the iodine be in excess.
complete saturation of the iodine, this red sub-
nust be dissolved in water, and then through
tion a current of chlorine is to be passed until
n takes place. Solution of Chloriodic Acid thus
is a clear liquid, provided neither of the elements
cess.
) C. It would seem from Davy's experiments
difficult to form Chloriodic Acid as a definite
nd. When the chlorine is in defect the sub-
solid, but when the quantity of chlorine is con-
e, both substances seem to rise in vapour,
still in a state of combination. The solution
gly acid properties and destroys vegetable blues.
) D. F. H. Unexamined, or unimportant.
) I. Chloriodic Acid seems to have a powerful
ction with some of the metals, for it is decom-
mercury, which renders experiments upon this
e extremely difficult and unsatisfactory.
) K. It seems impossible to combine this Acid
es, for whenever such were presented to it, the
as decomposed, muriatic and iodic Acid being
lt.
) L. On this head consult Iodine L, and Chlo-

) M. None at present; but Sir H. Davy, by
birds on bread soaked in the solution of this
oved that it is not poisonous like pure iodine. (*d.*

Subsect. 3.—*Hydriodic Acid.*

) A. This Acid was doubtless first produced
ring the experiments of M. Courtois or of MM
v.

Clement and Desormes, but its accurate examination was undertaken by M. Gay Lussac and Sir H. Davy. It would seem that the hydriodate of potash exists in the *Fuci* only and in some of the Sponges.

(238.) B. Hydrogen and iodine if placed in contact enter into combination upon a moderate elevation of temperature. But there are other and better processes for obtaining Hydriodic Acid which depend upon presenting the hydrogen to the iodine in a nascent state. Of these we prefer the following. Put into a small tube retort eight parts of iodine and one of phosporus, and let this mixture be slightly moistened with water. Then by the application of a very gentle heat the Hydriodic Acid comes over rapidly in the form of a Gas which may be collected over mercury, though mercury decomposes some of it: or it may be passed into water in which it is soluble, and may be kept for use as a test. Another excellent method is to diffuse iodine through water and then to pass a current of hydro-sulphuric Acid through the water: the hydrogen combines with the iodine, the Hydriodic Acid remaining in solution, and the sulphur is precipitated. Time should be allowed for the sulphur to subside, and any excess of Hydro-sulphuric Acid remaining in the liquid may be dissipated by the application of a moderate heat. In this manner, also, the Acid may with care be considerably concentrated. This Acid consists of one volume of iodine vapour + one volume of hydrogen.

(239.) C. Hydriodic Acid when pure is a colourless Gas, very acid to the taste, strongly reddening vegetable blues, and having a powerful smell, extinguishing combustion, and forming white fumes as it comes in contact with atmospheric air. Water absorbs this Gas with avidity, and by careful evaporation a solution of Specific Gravity 1.7 may be obtained. A red heat decomposes Gaseous Hydriodic Acid.

(240.) D. By admixture with oxygen Gas, Hydriodic Acid Gas is entirely decomposed. Water being formed, the iodine remains free.

(241.) E. By admixture with chlorine decomposition also takes place: the chlorine seizes upon the hydrogen to form hydrochloric Acid: and the iodine vapour gradually condenses into the solid form.

(242.) F. and H. Unknown.

(243.) I. Potassium, sodium, zinc, iron, mercury, and many other metals decompose this Acid: hydrogen is liberated, and metallic iodides are formed.

(244.) K. The hydrochloric, hydro-sulphuric, and sulphurous Acids do not affect the Hydriodic Acid when brought in contact with it, but concentrated sulphuric and nitric Acids cede a part of their oxygen to its hydrogen, so that from this double decomposition there results a deposit of iodine, sulphurous Acid Gas, or deutoxide of azote and water. Solutions of iron, also, in a high state of oxidation, throw down the iodine: as also some other metals which produce iodides.

There are also two compounds of the two varieties of phosphuretted hydrogen with Hydriodic Acid, and for these see (*l.*)

With bases the Hydriodic Acid forms Salts, which are all soluble in water, and for the most part crystallizable. For the properties of these we would refer our readers to Thomson's *Chemistry*, vol. ii. p. 277.

(245.) L. " Hydriodate of potash does not precipitate solutions of manganese, nickel, or cobalt. Hence the hydriodates of these metals are soluble in water. Gay Lussac is of opinion that all the hydriodates of the metals incapable of decomposing water are precipitated by hydriodate of soda. The precipitate of copper is greyish white; that of lead a fine orange yellow; that of protoxide of mercury greenish yellow; that of peroxide of mercury orange red; that of silver is white; that of bismuth moreen." Thomson. (*m.*)

(246.) M. None.

References in § 4.

(*a.*) Fyfe, *Edin. Phil. Journ.* vol. i. (*b.*) Ure, *Phil. Mag.* vol. l. (*c.*) Wollaston, *An. Phil.* O. S. vol. v. p. 237. (*d.*) Gay Lussac, *An. de Ch.* vol. xci. p. 7. (*e.*) Thenard, *Syst.* vol. i. (*f.*) Stromeyer, *An. Phil.* O.S. vol. vi. p. 312. and Gualtier de Claubry, *An. de Ch.* vol. xciii. p. 75. (*g.*) Majendie, *Essai sur la Préparation et Emploi de plusieurs nouveaux Médicamens*, Paris, 5th Edit. 1825. (*h.*) Davy, *Phil. Trans.* 1814, p. 86. (*i.*) Colin, *An. de Ch.* vol. xci. p. 262, and *An. de Ch.* vol. lxxxviii. and xc. (*k.*) Davy, *Phil. Trans.* 1815, p. 204. (*l.*) Dulong, *Mém. d'Arcueil*, vol. iii. p. 450; Houton Labillardiere, *Jour. de Pharmacie*, vol. iii. p. 454; Thenard's *Syst.* vol. i. p. 733. (*m.*) Thomson's *Syst.* vol. ii. p. 279, or Thenard's *Syst.* vol. ii. p. 637. (*n.*) Thomson's *Syst.* vol. ii. p. 274. (*o.*) *Quarterly Journal, &c.* vol. xvii. p. 381.

§ 5. *Bromine.*

Bromine.

(247.) A. Bromine was discovered by M. Balard of Montpelier, (*a.*) who recognised it by a peculiar yellow cloud which appeared in the solutions from which he precipitated iodine by starch. These solutions were obtained from the lixivium of the ashes of the *Fuci*, which had been burned for the purpose of obtaining their alkaline matter; and also from the bittern left after the evaporation of sea water. M. Balard considers that this substance exists in small quantity in sea water as a hydro-bromate of magnesia. Also in marine plants growing on the shores of the Mediterranean; and in the shell of the *Ianthina Violacea*. M. Liebeg has detected it in the saline springs of Theodorshall, near Kreutznach. (*b.*) Bromine is considered to be a simple substance, having properties intermediate between those of chlorine and iodine, which latter substance it ought to have preceded in our Synoptic Scheme. (4.)

(248.) B. The best process for obtaining Bromine is to pass a current of chlorine Gas through the bittern or the lixivium of marine plants, and afterwards to agitate a little ether with the liquid. The Bromine is taken up by the ether, which assumes a deep hyacinth red colour, and by being left quiet for a short time rises to the surface. This solution is to be decanted off, and mixed with caustic potash; it thus becomes colourless, and cubic crystals of hydro-bromate of potash are obtained upon evaporation.

To obtain Bromine from these crystals, let them be reduced to powder and mixed with pure peroxide of manganese. Put this mixture into a retort with a little sulphuric Acid, diluted with half its weight of water; by gentle distillation vapours of Bromine are disengaged, which condense in red drops of liquid; or, to assist the condensation, a small quantity of water may be put into the receiver. The water may afterwards be entirely separated by distillation from dry chloride of calcium.

Bromine may also be obtained in its liquid state, though not perfectly pure, by simply distilling it from the bittern after that liquid has been acted upon by chlorine as above described.

(249.) C. At ordinary temperatures Bromine is a liquid, of a blackish red colour in mass, but when in a thin film transmitting hyacinth red light. It congeals at about 0° Fahrenheit, (*c.*) and boils at about 116°.5 Fahrenheit. It is very volatile, emitting red vapours at ordinary temperatures; but it undergoes no change from either a red heat or from the action of the voltaic pile. It is absolutely a non-conductor of electricity. (*d.*) Combustion it will not support. It is soluble in water, alcohol, and readily so in ether. Like chlorine it discharges vegetable blues, but without reddening them. Its odour and taste are powerful and disagreeable, resembling chlorine. It corrodes animal matter, and produces a yellow stain on the skin, which shortly disappears; this colour is less intense than that produced by iodine. Specific Gravity 2.96. (Balard.)

(250.) D. No compound of Bromine and oxygen has been formed directly; and the only one that has been formed indirectly is the Bromic Acid. See subsect. 1. The affinity of Bromine for oxygen seems about equal to that which it exerts towards hydrogen; for oxygen cannot abstract hydrogen from Bromine; neither can Bromine decompose the vapour of water so as to possess itself of the hydrogen.

(251.) E. At ordinary temperatures Bromine unites with chlorine, producing a reddish yellow liquid, which is highly volatile, having a very penetrating odour and disagreeable taste. This liquid is soluble in water, apparently without undergoing decomposition. Alkalis, when added to this solution decompose it, producing bromic and hydro-chloric Acids.

(252.) F. Unknown.

(253.) G. With Bromine iodine seems to form two combinations. The one a crystalline substance, the other a Liquid. Iodide of Bromine is soluble in water. By adding alkalis to this solution, iodates and hydrobromates are produced.

(254.) H. The vapour of Bromine does not unite with hydrogen Gas by mere contact, but if a lighted candle or a piece of ignited wire be introduced into the mixture, combination takes place around the heated body, but without explosion, and without extending to the entire mass of the fluids. On mixing the vapour of Bromine with hydriodic Acid, hydro-sulphuric Acid, or phosphuretted hydrogen, they are respectively decomposed, and an Acid Gas, the hydro-bromic Acid, is produced. See subsect. 2. The affinity of Bromine for hydrogen is intermediate between the affinities of chlorine and iodine, for chlorine decomposes the hydro-bromic Acid; but Bromine will decompose the hydriodic Acid. Phosphorus unites with Bromine in two proportions; with sulphur in one proportion. M. Balard could not obtain a combination with pure carbon; but succeeded in forming a hydro-carburet of Bromine. M. Serullas has, however, succeeded in forming the Bromide of carbon. With selenion, Bromine has been also combined by M. Serullas.

(255.) I. With the metals the action of Bromine is much similar to that of chlorine. Antimony, tin, and potassium burn in it, the latter with great energy. M. Balard supposes that the soluble metallic Bromides are, like the soluble iodides and chlorides, converted into neutral hydro-bromates; and conversely, that the solutions of hydro-bromates are, by evaporation, converted

hydrous Bromides. The Bromides are all de-
sed by chlorine, which unites with the metal
the Bromine free. The attraction of Bromine
rcury is very strong, producing during combina-
onsiderable heat, but no light. M. Balard de-
the Bromides of lead, mercury, silver, gold, and
m: those of arsenic and bismuth are described
Serullas. (*c.*)

6.) K. The only actions that can take place be-
Bromine and the Acids, is of the nature of
positions: these, however, at present require
examination.

7.) L. Bromine, or its combinations, produce no
whatever upon solutions of starch, by which it
rly distinguished from iodine. An effort has
nade to employ it as a test for all the vegetable
; but complete success has not been obtained.
The Bromate of potassa affords no precipitate
he Salts of lead; but a white one with the nitrate
er, and a yellowish white one, soluble in nitric
with the proto-nitrate of mercury. By these
teristics it is well distinguished from the chlorate
ate of the same alkali.

8.) M. Bromine appears to possess poisonous
ties; for by placing a drop of it upon the beak of
the animal was destroyed.

Subsect. 1.—*Bromic Acid.*

9.) When Bromine is agitated with a concentrated
n of potassa, or when the solid alkali is mixed
n ethereal solution of Bromine, two Salts, the
te and hydro-bromate of potassa, are formed. By
ation, these are obtained in separate crystals;
of the hydro-bromate being cubic, and those of
romate acicular. The Bromate of potassa is
ted from the hydro-bromate by being very spar-
soluble in cold water, while the latter is readily
The Bromates possess properties analogous to
of the iodates and chlorates. Thus the Bromate
assa when heated becomes Bromide of potassium,
n being disengaged; it deflagrates when thrown
ited charcoal, and when mixed with sulphur it
tes upon percussion. The Acid of the Bromates
mposed by substances that abstract oxygen, such
sulphurous and hydro-sulphurous Acids. The
tes also are decomposed by the hydro-chloric and
bromic Acids.

Bromic Acid is obtained in a separate state, by
dilute sulphuric Acid to the Bromate of barytes.
Bromate may either be formed from the Bromate
assa, or directly upon the general principle, that
alkaline earths, except magnesia, seem to form
solutions containing Bromine the Bromic and
bromic Acids, which may be separated as above
bed.

Salts of lead produce no precipitate with solu-
of Bromate of potassa, but abundant ones with
dro-bromate of that alkali. M. Balard supposes
omic Acid to contain five atoms of oxygen + one
of Bromine.

Subsect. 2.—*Hydro-bromic Acid.*

0.) The action between bromine and hydrogen
en already noticed, (254.) but the best process
rming Hydro-bromic Acid is to mix together a
quantity of phosphorus and bromine in a retort;
moisture should be present; and by application of a gentle heat Hydro-bromic Acid Gas is copiously evolved. This Gas may be collected over mercury or dissolved in water.

Part II.

The Hydro-bromic Acid Gas has a pungent odour and an acid taste. On meeting with moist air, it produces very dense white vapours. It is not decomposed by being passed through a red-hot tube, even when mixed with oxygen. Chlorine immediately decomposes it, though iodine does not. Potassium decomposes it at all temperatures; and tin also when heated. Nitric Acid decomposes the watery solution of Hydro-bromic Acid with evolution of bromine; and the mixed liquid will dissolve gold. The alkalis, earths, the oxides of iron, and the peroxides of copper and mercury unite with Hydro-bromic Acid to form true Hydro-bromates; but with the oxide of silver and the protoxide of lead, a double decomposition takes place, producing a metallic bromide and water.

Iron, zinc, and tin dissolve in Hydro-bromic Acid; hydrogen being evolved. Hydro-bromic Acid consists of equal volumes of its two elements in the Gaseous state.

References in § 5.

(*a.*) Balard, *An. de Ch. et Ph.*, vol. xxxii. p. 337. (*b.*) Liebeg, *An. de Ch. et Ph.*, vol. xxxiii. p. 331. (*c.*) Serullas, *An. de Ch. et Ph.*, vol. xxxiv. p. 95; vol. xxxv. p. 340; and vol. xxxviii. p. 318. (*d.*) De la Rive, *An. de Ch. et Ph.* vol. xxxv. p. 160. (*e.*) D'Arcet and Chevruel, *An. de Ch. et Ph.*, vol. xxxviii. p. 82.

CHAPTER III

Non-metallic (Electro-positive ?) Elements.

The substances which we shall consider in this Chapter are in number eight, exclusive of some important compounds, which will also be noticed as proximate elements; *viz.* silicon, hydrogen, carbon, boron, phosphorus, sulphur, selenion, and nitrogen. Of these, hydrogen and nitrogen are at present considered permanent Gases; but there is some reason to conclude from analogy, that, by enormous pressure, these and all Gaseous fluids might be reduced to the liquid form. The six remaining bodies are solid at our ordinary temperatures. Phosphorus, sulphur, and selenion are fusible and volatile; while silicon, boron, and carbon are generally considered as infusible and fixed. Not one of these has any action on oxygen at the ordinary atmospheric temperatures. Nitrogen has none at any temperature, however elevated; but hydrogen, boron, carbon, phosphorus, sulphur, and selenion are capable of combination with it, heat and light being evolved.

That silicon may be converted into an Acid is doubtful. Hydrogen is acidifiable by chlorine, fluorine (?) iodine, and bromine. Carbon, boron, phosphorus, and nitrogen by oxygen only; but sulphur and selenion by both oxygen and hydrogen.

§ 1. *Silicon.*

Silicon.

(261.) A. The name Silicon has been proposed by Dr. Thomson (*a.*) for the base of the well-known earth silica. When Sir H. Davy first decomposed that body, he gave to its base the name of silicium, and such it continues with M. Thenard, and those who consider this base entitled to rank among the metals. But if, with the greater number of Chemists, we consider this base analogous to boron and carbon, and destitute of metallic properties, Silicon is the more appropriate term.

"Sir H. Davy, after having succeeded in decomposing the fixed alkalis and alkaline earths by the action of the Galvanic battery, was naturally led to try the effects of the same powerful agent upon silica. But his experiments were not attended with success. (*b.*) But the analogy between silica and other bodies containing oxygen is so great, that it was universally considered as a compound of oxygen and a combustible base. Berzelius succeeded in separating this base from silica, and uniting it to iron, (*c.*) and his experiments were successfully repeated by Professor Stromeyer. (*d.*) About the end of 1813, Sir H. Davy succeeded in obtaining the base of silica in a separate state, although he was not able to collect it and examine its properties in detail." (*e.*) Thomson. (*a.*) Berzelius completed the evidence of the nature of this substance in 1824. (*aa.*)

(262.) B. Davy decomposed silica by passing excess of potassium through it in a heated tube of platinum. The potassium was converted into potash, through which the Silicon was disposed in the form of a dark-coloured powder.

Berzelius says nothing is more easy than to procure Silicon; the method by which it is obtained is this. The double fluate of silica with potassa or soda, heated almost to a red heat, for the purpose of driving off the hygrometric water, is introduced into a tube of glass closed at one end. Some fragments of potassium are introduced, and care is taken to mix the potassium with the powder, by applying a heat sufficient to fuse the metal, and gently tapping the tube. The heat of a lamp is then applied, and before the mixture arrives at a red heat there is a feeble detonation, and the Silicon is produced. The mass is then left to cool, and afterwards washed with water as long as any thing is dissolved. At first there is a disengagement of hydrogen Gas, because a siliciuret of potassium is obtained, which cannot exist in water. The washed substance is a hydruret of Silicon, which at a red heat burns vividly in oxygen Gas; though the Silicon does not become oxidated. This hydruret is then to be put into a covered platinum crucible, and heated by slow degrees up to redness. The hydrogen becomes oxidated alone, and the Silicon will no longer burn in oxygen, though chlorine attacks it readily. A small quantity of silica is produced, which may be dissolved by fluoric Acid. If the Silicon has not been well heated to redness, the Acid dissolves it with slow disengagement of hydrogen. (*aa.*)

(263.) C. Silicon is a dark nut-brown powder, having no metallic lustre. It is a nonconductor of Electricity, and is infusible before the blowpipe.

(264.) D. Silicon does not burn in atmospheric air, or oxygen Gas, but it indirectly will form a very firm compound with that substance; thus producing the well-known earth silica, which exists in great abundance in Nature. See subsect. 1.

(265.) E. Silicon readily unites with chlorine as already stated.

(266.) F. With fluorine, Silicon unites to form an Acid Gas which has been already noticed. (184.)

(267.) G. Unexamined.

(268.) H. Silicon unites with hydrogen, but its habitudes with other bodies of this class require investigation.

(269.) I. There is great reason to suppose that Silicon may unite with most of the metals, but as yet its combinations with iron and potassium are all that are mentioned.

(270.) K. Silicon is neither oxidated nor dissolved by the nitric, hydro-chloric, sulphuric, or fluoric Acids; but it is readily soluble in even a cold mixture of the nitric and fluoric Acids.

Silicon is not changed by being ignited with chlorate of potassa. It does not deflagrate in nitre, until the temperature is raised high enough to decompose the Acid; and then oxidation takes place in consequence of the concurrent affinities of oxygen for Silicon, and of silica for the disengaged potash. By a similar play of affinities, Silicon burns vividly when brought into contact with carbonate of potassa or soda, even below a red heat. When dropped upon fused hydrate of potassa, soda, or baryta, hydrogen is evolved with such rapidity as to produce explosion.

(271.) L. M. All that need be said on these heads will be found in subsect. 1. L. and M.

Subsect. 1.—*Silica.*

Silica.

(272.) A. From the element silicon we proceed to its oxide Silica, which has long been known as one of the earths, and forms, in its various combinations with other mineral bodies, the largest proportion of the substance of our planet. "Quartz, chalcedony, flint, sand, and some other minerals consisting principally of Silica, have the property of melting into glass when strongly heated with potash or soda, and, therefore, were classed together by the early Mineralogists under the name of vitrifiable stones. Mr. Pott, who first described the properties of these minerals in 1746, gave them the name of Siliceous stones, supposing them to be chiefly composed of a peculiar earth, called Siliceous Earth, or Silica. This earth was known to Glauber, who describes the method of obtaining it from quartz. But it was long before its properties were accurately ascertained. Geoffroy endeavoured to prove that it might be converted into lime, (*f.*); Pott (*g.*) and Beaume (*h.*) that it might be converted into alumina; but these assertions were refuted by Cartheuser, (*i.*) Scheele, (*k.*) and Bergman. (*l.*) To this last Chemist we are indebted for the first accurate description (*m.*) of the properties of Silica." (*n.*)

(273.) B. Pure Silica is obtained by fusing pulverized flint with thrice its weight of caustic potash in a silver crucible. The spongy mass thus obtained is to be dissolved in water, and then super-saturated with muriatic Acid, and slowly evaporated to dryness. By subsequent affusion of water the alkaline Salt is removed, and the Silica remains pure.

(274.) C. Thus obtained Silica is a white powder, without taste or smell. Not soluble in water. "But when the compound of Silica and potash is dissolved in water, and sufficiently diluted, the Silica cannot be precipitated from it by any addition of Acid; showing that in this state it is really soluble in water." After it has been thoroughly dried it seems quite insoluble; but when fresh precipitated, and still moist, it dissolves, according to Kirwan, in 1000 parts of distilled water; and it exists naturally in minute proportions in some mineral waters, such as the Geyser springs in Iceland.

Silica is infusible, except by the heat of the Gas blowpipe. It is not volatile under our ordinary processes, though it would seem from some observations of Bergman, and also from a more recent notice, that it is capable of volatilization by intense heat. (*x.*)

The crystallization of Silica forms a marked feature among its Physical properties. In Nature it is found in this state abundantly. There must be few who have not admired the beautiful hexagonal prisms of quartz, terminated by hexahedral pyramids, which occur in every Country of the Earth. This is rock crystal in its most common secondary form. We are frequently led to suppose that the process of the formation of crystals in the earth is a very tedious process, requiring the quiet operation of Ages to accomplish, but Chemistry offers many reasons to induce us to suspect that this may easily be overrated. The following confirmation of this view is taken from Thomson's *System.* "There are two methods of imitating these crystals by art. The first method was discovered by Bergman. He dissolved Silica in fluoric Acid, and allowed the solution to remain undisturbed for two years. A number of crystals were then found at the bottom of the vessel, mostly of irregular figures, but some of them cubes with their angles truncated. They were hard, but not to be compared in this respect with rock crystal. (*o.*) The other method was discovered by accident. Professor Seigling of Erfurt had prepared a *Liquor Silicum,* which was more than usually diluted with water, and contained a superabundance of alkali. It lay undisturbed for eight years in a glass vessel, the mouth of which was only covered with paper. Happening to look at it by accident, he observed it to contain a number of crystals, on which he sent it to Mr. Tromsdorf, Professor of Chemistry at Erfurt, who examined it. The liquor remaining amounted to about two ounces. Its surface was covered by a transparent crust, so strong that the vessel might be inverted without spilling any of the liquid. At the bottom of the vessel were a number of crystals, which proved on examination to be sulphate of potash and carbonate of potash. The crust on the top consisted partly of carbonate of potash, and partly of crystallized Silica. These last crystals had assumed the form of tetrahedral pyramids in groups: they were perfectly transparent, and so hard that they struck fire with steel." (*p.*)

(275.) D. E. None.

(276.) F. See (184.)

(277.) G. None.

(278.) H. None of the substances belonging to this class have any action on Silica.

(279.) I. Potassium and sodium are known to be capable of decomposing Silica, possessing themselves of its oxygen: the other metals have no action upon it.

(280.) K. It is under this head chiefly that we find the marked characteristics of Silica. It does not unite with Acids in general, from whence it would seem incapable of performing the part of a base: a strong argument against its being the oxide of a metal. There is, however, one Acid with which it manifests some singular properties, this is the hydro-fluoric, the only one capable of dissolving it. If finely powdered Silica be mixed with hydro-fluoric Acid the whole compound instantly assumes the Gaseous form. Silica fuses also into a Glass with solid phosphoric or boracic Acid.

On the other hand, Silica possesses strongly acid properties towards the alkaline bases, and on this ground Mr. Smithson was led to consider it actually an acid body; and to argue that it performed the part of an Acid in its union with many earthy bases. In this view of the subject many mineral bodies are a sort of earthy Salts. (*q.*) This idea has been ably supported by Berzelius. (*r.*)

To proceed then to the combination of Silica with alkalis. It readily dissolves in solutions of either of the fixed alkalis, though ammonia has no effect upon it, either in the Gaseous or liquid form. When Silica is fused with potassa, if the latter be in great excess the compound is soluble in water forming the *Liquor Silicum* of old writers: but when the Silica is in great excess Glass is the resulting compound. Baryta seems to unite with Silica by fusion but imperfectly, though the affinity between the substances is considerable; for, according to Morveau, if barytic water be added to dilute *Liquor Silicum,* a precipitate is formed in which both earths are united. (*s.*) The compounds resulting from fusing these earths together in various proportions have been examined by Mr. Kirwan. (*t.*)

The habitudes of strontia with Silica are similar to those exhibited by barytes. "Equal parts of magnesia and Silica melt with great difficulty into a white enamel when exposed to the most violent heat that can be produced. (*u.*) They are infusible by inferior degrees of heat in whatsoever proportion they may be mixed. (*v.*)

If lime water be added to a solution of Silica in potash, a precipitate falls down containing the two earths in a state of combination. (*w.*) The compounds formed by fusing these two substances together, have been examined by Mr. Kirwan: (*t.* p. 56:) when the earths were in equal quantities an imperfect sort of enamel was formed. Silica has a strong affinity for alumina; for, according to Morveau, (*s.* p. 249,) if equal parts of Silicated potash and Silicated alumina, both in solution, be mixed together, a brown cloud appears, which by gentle agitation spreads throughout the whole Liquid. In the course of an hour this cloud gelatinizes. These two earths, however, cannot be heated so as to run into fusion. (*v.* and *t.*)

(281.) L. Silica is recognised by its insolubility in all Acids except the fluoric: by forming a compound entirely soluble in water upon calcination with twice its weight of potash in a silver crucible. The solution when concentrated forms a coagulum upon the addition of an Acid.

(282.) M. The uses of Silica are numerous and important. A variety of rock crystal, which occurs in rolled masses in the Island of Madagascar, being beautifully diaphanous, is cut for spectacles, and goes by the common name of crystal. The rich amethysts that come from Spain, Siberia, and Brazil, are only the same substance naturally coloured by the oxide of manganese. The manufacture of Glass will require a more extended detail in another part of this Work: for the present, therefore, we must be satisfied with stating, that two parts of Silica fused with from one to one and a half of carbonate of potash or soda, forms this most beautiful and useful substance. The more pure the ingredients the more clear will be the Glass; but as both the substances employed are not previously purified by the tedious and costly Chemical processes, the manufacturer is obliged to resort to other artifices for the improvement of his metal, as the fused compound is technically called. The finer kinds of Glass are made from pounded flint and the best pearl ash, or sometimes

Chemistry. fine washed white sand is used in place of the pounded flint. Window Glass is made from sand and kelp. Green bottle Glass is made from sea sand and the refuse of the soap-maker's lees, which contain a large proportion of lime. The less alkali is employed the harder is the Glass, but a greater heat is required for its fusion. Besides these, which are the essential ingredients, oxide of lead is added, which promotes the fusion of the materials; renders the Glass more dense and ductile, adds to its refractive power, and therefore to its brilliancy, and allows of its taking a higher polish.

Black oxide of manganese has been called the Glass-maker's soap, because it greatly improves the transparency of Glass. This it does by a mutual compensation of properties with the oxide of iron which is always present in both the main ingredients of Glass. For iron in a low state of oxidation gives to Glass a green tint, but in a high state of oxidation it either does not enter into fusion with the Glass, but is removed among the scoriæ, or when fused it does not communicate colour. On the other hand, the black oxide of manganese produces a violet colour; but in a lower state of oxidation it communicates no colour at all. When the two, therefore, meet in the formation of Glass, the iron gains some oxygen which the manganese loses, and both are reduced to that state which is most favourable to the transparency of the Glass.

By some variations in the composition, chiefly arising from the addition of several metallic oxides, certain kinds of Glass are formed in imitation of precious stones. The colourless variety is technically called paste, and by the addition of other metallic oxides all the coloured gems are imitated. (*y.*)

Porcelain also consists of various proportions of Silica and other earths fused together, but in this compound alumina predominates.

Enamels consist of Glass fused with large proportions of the oxides of tin and lead. (*z.*)

References in § 1.

(*a.*) Thomson, *Syst.* vol. i. p. 249. (*b.*) Davy, *Phil. Trans.* 1808. (*c.*) Berzelius, *Afhand.* vol. iii. p. 117. 1810. (*d.*) Stromeyer, *Gilb. An.* vol. xxxvii. p. 335. vol. xxxviii. p. 321. (*e.*) Davy, *Phil. Trans.* 1814, p. 67. (*f.*) *Mem. Par. Ac.* 1746, p. 286. (*g.*) *Lithogeog.* p. iii. *Preface* (*h.*) *Mém. de Chim.* (*i.*) *Miner. Abb.* (*k.*) Scheele's *Essays*, vol. i. p. 191. (*l.*) *Sur les Terres Géoponiques*, *Opusc.* vol. v. p. 59. (*m.*) *Opusc.* vol. ii. p. 26. (*n.*) Thomson, *Syst.* vol. i. p. 248. (*o.*) Bergman, *Opusc.* vol. ii. p. 32. (*p.*) Nicholson's *Journ.* vol. i. p. 217. (*q.*) *Phil. Trans.* 1811, p. 176. (*r.*) *Nouveau Syst. Min.* (*s.*) *An. de Ch.* vol. xxxi. p. 250. (*t.*) Kirwan, *Min.* vol. i. p. 57. (*u.*) Lavoisier, *Mém. Acad. Par.* 1787, p. 598. (*v.*) Achard, *Mém. Acad. Berlin*, 1780, p. 33. (*w.*) Gadolin, *An. de Ch.* vol. xxii. p. 110. and Morveau, *An. de Ch.* vol. xxxi. p. 150. (*x.*) *Geo. Trans.* vol. ii. (*y.*) *Jour. de Phys.* vol. xxviii. p. 502. (*z.*) Aikin, *Chem. Dict. Enamel.* (*aa.*) *An. de Ch. et Ph.* vol. xxxvi. p. 41.

§ 2.—*Hydrogen.*

Hydrogen. (283.) A. With regard to the discovery of Hydrogen Gas, Dr. Thomson states that "Mayow, (*a.*) Boyle, (*b.*) and Hales procured it in considerable quantities, and noted a few of its mechanical properties. Its combustibility was known about the beginning of the XVIIIth century, and was often exhibited as a curiosity. (*c.*) But Mr. Cavendish (*d.*) ought to be considered its real discoverer; since it was he who first examined it, who pointed out the difference between it and atmospheric air, and who ascertained the greatest number of its properties." (*e.*)

Hydrogen Gas is frequently generated in considerable quantities in mines, or in other parts of the Earth where metallic bodies exist. (*f.*)

(284.) B. Hydrogen Gas is readily obtained by acting upon iron turnings or small nails with sulphuric Acid, diluted with five or six times its weight of water. Granulated zinc may also be employed, in which case the dilute Acid may consist of eight-ninths of water. In both cases the metal is to be placed in a retort or glass proof, and the Gas, which is rapidly evolved, may be collected in jars over the water-trough. A very convenient instrument for obtaining and preserving a constant supply of this Gas in a laboratory was contrived by Gay Lussac, and is described in the *Annales de Chimie et de Phisique.* (*g.*) Hydrogen Gas, however, thus obtained from metals, is not absolutely pure, (*h.*) and requires to be washed with a solution of caustic potassa. Berzelius discovered that Hydrogen Gas, produced from iron filings and dilute sulphuric Acid, might be deprived of all scent by being passed through pure alcohol; and that when the alcohol is diluted with water, and kept a few days, the odorous volatile oil is separated. (*i.*) Hydrogen Gas may also be procured in very considerable quantities by passing the vapour of water over coils of iron-wire heated to redness in a gun-barrel: the iron undergoes oxidation and the Hydrogen is set free.

(285.) C. Pure Hydrogen Gas is free from smell and taste. Water will absorb only about two per cent. of its own volume. It is unaltered by heat and electricity. Its action on the rays of light is more highly refractive than that of any other Gas. It is inflammable, and the lightest of all known substances. It will not support animal life, though its properties do not seem to be poisonous. When breathed from a bladder or oil-silk bag, it renders the tone of the voice of a much higher pitch than usual: an effect which shortly goes off again. (*p.*)

The combustion of Hydrogen with oxygen affords many interesting particulars, for the full details of which we can only point out the references. (*k.*) Water is the sole produce of this combustion, subsect. 1. The proportion in which these two elements unite is precisely two volumes of Hydrogen + one volume of oxygen.

When Hydrogen Gas, issuing from a small orifice, is burned in common air, and a glass tube is held over the flame, musical sounds are produced. (*m.*)

(286.) D. Hydrogen and oxygen do not unite when merely placed in contact with each other, but by violent compression. M. Biot found a mixture of these Gases might be made to unite. The combination took place with evolution of light and heat. Biot also found that a pressure of thirty atmospheres, produced by sinking a vessel of the mixed Gases to a depth of one hundred and fifty fathoms in the sea, did not cause their union. (*n.*)

The combination of these Gases may also be produced by the electric spark, by a glowing coal, or a red-hot wire; but if the heat of these bodies be below redness, the combination takes place gradually and silently. When the Gases are in the just proportion to form water, the detonation is very violent: upon this combination depends the eudiometer of Volta, and the Philosophical experiment of the air-pistol.

Dŏbereiner discovered that the sub-oxide of platinum, and also the pulverulent metallic platinum, obtained by heating the ammonia-muriate, would, if plunged into the mixed Gases, condense the Hydrogen in its pores so violently as to become red hot, by which means instantaneous combustion is produced. It has been proposed to employ this method also for eudiometry. (*l.*) Upon this property is founded an elegant instrument for obtaining an instantaneous light.

The intense heat developed by the combustion of Hydrogen with oxygen has been applied to the construction of a blowpipe for the fusion of refractory bodies, and there is scarcely any substance in Nature that can resist its action. See BLOWPIPE, in the Miscellaneous department of this Work, or Professor Clarke's *Treatise on the Gas Blowpipe.* (*o.*)

Hydrogen and oxygen may also be made to unite in a proportion different from that in which they form water. See subsect. 2.

(287.) E. The union of Hydrogen with chlorine producing hydro-chloric, or as it has long been called, muriatic Acid, has been already noticed, chap. ii. sect. 2. subsect. 6.

(288.) F. See chap. ii. sect. 3. subsect. 1.

(289.) G. See chap. ii. sect. 2. subsect. 3.

(290.) H. Hydrogen unites with carbon, phosphorus, sulphur, selenion, and nitrogen. These compounds, as they form proximate elements, will for the most part be described at length hereafter.

(291.) I. Hydrogen forms with potassium two compounds; the solid hydruret discovered by MM. Gay Lussac and Thenard, (*q.*) and also a Gaseous compound described by M. Sementini of Naples. With arsenic, also, two analogous compounds are formed; the one solid, the other Gaseous. Tellurium forms with Hydrogen two compounds; the one Gaseous, *Telluretted Hydrogen,* which has acid properties, (*r.*) the other a white powder discovered by Ritter, but at present little known.

(292.) K. At ordinary temperatures Hydrogen does not act upon the metallic oxides; nor indeed at any temperature on those of the first class of metals. At a heat below redness, it reduces all the higher oxides of the second class of metals to the state of protoxides. At different degrees of heat it reduces all the oxides of the other classes to the metallic state; the products being the pure metal and water.

(293.) L. Hydrogen is principally recognised by its property of combustibility, and by its union with oxygen, determinable by the electric spark in Volta's eudiometer.

(294.) M. None.

Subsect. 1.—*Water.*

(295.) The Chemical history of this well-known and essential substance, formerly called one of the four elements of the Earth, possesses considerable interest; both with regard to its actual properties, and the elaborate researches to which it has given rise.

Pure water is a colourless Liquid, having neither scent nor taste. It refracts light very strongly, is an imperfect conductor of electricity, and a very slow conductor of heat. It is now admitted to be a compressible fluid. (68.) Its Specific Gravity is called one, being made the unit of the scale to which the gravity of all other solid and liquid bodies is referred. Water is obtained in the greatest purity by slow distillation; but it is also sufficiently pure for many purposes when procured by melting snow, or by collecting rain water at a distance from houses or large towns. One cubic inch of water at 60° Fahrenheit and 30° in Ber. weighs 252.525 grains. Its weight is 828 times that of an equal volume of atmospheric air under the same circumstances.

The decomposition of Water may be effected in various ways. By submitting it to the action of a Voltaic battery, the two constituent Gases oxygen and hydrogen may be obtained separately. The same may be performed by a current of electricity from the common electrical machine. (*s.*)

The hydrogen may be obtained in the Gaseous form by passing steam over coils of iron-wire made red hot in a gun-barrel, or in a porcelain tube. In this case the oxygen assumes the solid form in combination with the iron.

To obtain the oxygen Gas alone, let a few sprigs of mint be placed in an inverted jar filled with Water over the pneumatic trough; as long as the vital functions of the plant are going on hydrogen is taken up by its leaves, pure oxygen Gas is evolved, and is collected in the jar.

The converse operation of the synthesis of Water is effected by mixing together oxygen and hydrogen Gases, and then applying a lighted taper, a piece of spongy platinum, or by passing an electric spark through the mixture. This experiment requires care, as the detonation of the mixed gases is very violent.

The just proportion, so as to leave no residuary Gas, is one volume of oxygen Gas + one volume of hydrogen Gas. If a jet of hydrogen Gas be lighted, and then an empty glass-balloon be inverted over it, the Water that is formed by its union with oxygen will condense in drops of Water on the sides of the balloon. It is now generally admitted that Water consists of precisely two volumes of hydrogen combined with one volume of oxygen, or by weight eight parts of oxygen + one part of hydrogen; or, according to the present views of the atomic theory, of one atom of each of these elements. The atom of Water, therefore, upon the hydrogen scale = 9

Water generally contains within its pores atmospheric air; and it is capable of absorbing various proportions of the different Gases. (*t.*) It exists also at all times in the atmosphere in the state of vapour; the quantity differing greatly at different temperatures. Pulverulent substances also absorb and retain considerable quantities of aqueous vapour. (*u.*) Water is one of the most universal solvents in Nature. It enters also frequently into combination with other substances, and assumes the solid form; of this the slaking of lime is an example; as also the common hydrates of potash, soda, &c. which, in appearance, are quite dry. The point at which Water has its maximum density is generally stated to be 39° Fahrenheit, but M. Biot places it at 38°.16 Fahrenheit. (*v.*) It congeals at 32° Fahrenheit, and boils at 212° Fahrenheit, Ber. 30°, but it rises in vapour at much inferior degrees of temperature.

Deutoxide of Hydrogen.

Subsect. 2.—*Deutoxide of Hydrogen.*

(296.) This substance was discovered by M. Thenard in July 1818. It is obtained from the peroxide of barium by a process of such delicacy, that it would not be possible to give, in the limits to which we are confined, any serviceable outline of it. We must, therefore, refer to the original *Memoirs* of M. Thenard. (*w.*)

The Deutoxide of Hydrogen is limpid, like water; has scarcely any smell. It gradually destroys the colour of papers stained with vegetable blues. It readily attacks the epidermis, whitens it, and causes a pricking sensation, the continuance of which varies in different individuals. Applied to the tongue it produces similar effects, together with a sort of slightly metallic taste. The elastic force of its vapour is much less than that of water, at any given temperature. It will entirely rise in vapour, even at low temperatures, though but slowly. Thenard was not able to freeze this Liquid by any degree of cold that he could produce. It must always be kept surrounded with ice, for it decomposes rapidly at a temperature of 58° Fahrenheit; and the heat of boiling water is sufficient to produce an explosion from the rapidity of the decomposition. The Specific Gravity of this Liquid is 1.425. It will mix with water, but if poured gently into that Liquid it passes through it like sirop. From the analysis of M. Thenard it appears that the Deutoxide of Hydrogen contains twice as much oxygen as the protoxide; that is to say, two atoms of oxygen $= 16 +$ one atom of hydrogen $= 1$, so that the weight of its atom $= 17$.

Light does not produce any very marked change upon this Liquid. The metals act upon it variously: some abstract a portion of its oxygen and reduce it to the state of water; others set a part of the oxygen free and take the remainder into combination; while others liberate all the oxygen without possessing themselves of any of it; and a few seem to possess no action upon it whatever. The Acids, especially the stronger ones, render the combination between its elements more firm. By the Voltaic pile it undergoes decomposition like water, as must be expected.

References to § 2.

(*a.*) *Tractatus Quinque*, p. 163. (*b.*) Shaw's *Boyle*, vol. iii. p. 21. (*c.*) Cramer's *Elementa Docimasiæ*, vol. i. p. 45. and Wasserberg, *Inst. Chem.* vol. i. p. 184. (*d.*) *Phil. Trans.* 1766, vol. lvi. p. 141. (*e.*) Thomson's *Syst.* vol. i. p. 217. (*f.*) *Phil. Trans. abr.* vol. i. p. 169. and *Journ. de Mines*, vol. iii. p. 13, 81. (*g.*) Vol. v. p. 300. (*h.*) Donovan, *Phil. Mag.* vol. xlviii. p. 138. (*i.*) Berzelius, *Qu. Journ.* vol. xvii. p. 380. *An. Phil.* N. S. vol. viii. p. 329. (*k.*) Cavendish, *Phil. Trans.* vol. lvi.; Grothus, *An. de Ch.* vol. lxxxii. p. 37; Davy *On Flame*, *Phil. Trans.* vol. cvi. p. 115; Davy, *Phil. Mag.* vol. xxxi. p. 3; Ure, *An. Phil.* vol. xii. p. 381. (*l.*) Döbereiner, *An. de Ch. et Ph.* vol. xxiii. and xxiv.; also *An. Phil.* N. S. vol. ix. p. 313; Grothus, *An. de Ch* vol. lxxii.; Davy *On Flame*; Henry, *Phil. Trans.*; Turner, *Edin. Phil. Journ.* 1824. (*m.*) Nich. *Journ.* vol. i. p. 129. and vol. iv. p. 23. (*n.*) Biot, Nich. *Journ.* vol. xii. p. 212. (*o.*) Hare, *An. de Ch.* vol. xlv.; Clarke *On the Gas Blowpipe*; Skidmore, Silliman's *Journ.* vol. v. p. 347. (*p.*) *Journ. of Science*, vol. ix. p. 182. (*q.*) *Recherches*, vol. i. p. 176. (*r.*) Davy's *Elements*, p. 410. (*s.*) Pearson, *Phil. Trans.* 1797. (*t.*) Dalton, *Syst.* p. 271. Saussure, Thomson's *An.* vol. vi. p. 340; Dalton, Thomson's *An.* vol. vii. p. 215. (*u.*) Berzelius, *An. de Ch.* vol. lxxxix. p. 118. (*v.*) Biot, Thomson's *An.* vol. ix. p. 434. (*w.*) Thenard, *An. de Ch. et Ph.* vols. viii. and ix. or *An. Phil.* N. S. vols. xiii. xiv. xv.; *Qu. Journ.* vols. vi. and viii.; *Mem. Acad. Par.* 1818; or Thenard *Syst.* Ed. 5. vol. ii. p. 42.

§ 3.—*Carbon.*

(297.) A. Carbon is seen commonly in two forms; both which consist of this element in considerable purity, common charcoal, and the diamond. Unlike as these two substances appear to each other, it has not yet been proved that they differ, except in the state of their aggregation. Newton, by a beautiful generalization deduced from Optical properties, suspected the presence of a combustible principle in the diamond. The experiments of the Florentine Academicians, in 1694, and those of others made subsequently, confirmed his supposition. (*b.*) Guyton first showed that the combustible principle was Carbon. (*a.*) Numerous experiments of this sort were made in different parts of Europe: of these, the best were by Mr. Tennant, the late Professor of Chemistry in the University of Cambridge, Messrs. Allen and Pepys, and Sir H. Davy; and all tended to prove that, in the combustion of the diamond, oxygen is taken up, and that a Gas consisting of this substance combined with Carbon is the product. (*c.*) Carbon exists, also, in considerable quantity in plumbago, a mineral consisting essentially of this substance combined with a small quantity of iron. It forms the chief element in all vegetable matter, and exists in various proportions in several animal substances.

(298.) B. Charcoal is generally now obtained by burning heaps of fagot wood in a sort of stack covered with turf, or still better by distilling the wood in cylindrical iron retorts: one product obtained by this method is the pyroligneous Acid, sold as vinegar and possessed of valuable antiseptic properties. (*d.*) *Lamp black* is a sort of charcoal, being the soot collected by burning the refuse resin procured in making turpentine. *Ivory black* is the carbonaceous matter obtained by the incineration of bones. *Coke* is a sort of impure charcoal, obtained by the close combustion of coal; and contains sulphur with much earthy matter. Charcoal for Chemical purposes may be obtained by burning box or alder-wood, or pieces of leather in a crucible covered with sand. It may be had in still greater purity by incinerating sugar or starch, or by passing the vapour of turpentine or spirit of wine through a red-hot porcelain tube. Carbon is at present deemed a simple ultimate element.

(299.) C. Carbon is a solid, even at the greatest elevations of temperature that we can command in our furnaces; still it seems proved, that by the powers of the Gas blowpipe it may be fused. And some recent experiments made with the Galvanic deflagrator by Professor Silliman and others, seem to attest that it is capable both of fusion and volatilization. (*e.*) Charcoal is a slow conductor of caloric, but conducts electricity readily. The Specific Gravity of the diamond is 3.52. The Specific Gravity of charcoal is generally stated much below the truth, in consequence of the porous nature of that substance; but recent experiments, in which that source of error is obviated, have assigned to it a Specific Gravity, equal at least to that of the diamond.

ıre Carbon is insoluble, and has neither smell nor
Charcoal, in consequence of its numerous pores,
able of absorbing and even condensing within itself
considerable quantities of Gaseous fluids; but these
tities differ for different Gases. On this point the
iments of Saussure seem the most satisfactory;
thers will be found by reference. (*f.*) It has also
at tendency to absorb moisture from the atmo-
e, and in this respect the different woods vary in
powers. (*g.*)

)0.) D. In atmospheric air charcoal will just burn,
small piece will not keep up a state of combustion
ut a current of air, or the aid of adventitious heat.
ygen, however, a piece of charcoal, heated pre-
ly, burns with vigour. The diamond will burn in
spheric air when heated on a muffle; and in
en Gas it continues to support its own combus-
if previously heated by being placed in the focus
ens. It burns, also, by being thrown into melted
The produce of this combustion is Carbonic
See subsect. 2. With oxygen, also, another com-
d may be formed, to which the name of Carbonic
may be given. See subsect. 1.

)1.) E. If charcoal be ignited in chlorine Gas no
ination is produced, but by an indirect process
Faraday succeeded in forming two chlorides of
on, and another such combination has been sub-
ntly discovered.

efiant Gas consists of one atom Carbon + one
hydrogen. If this Gas be mixed with an equal
ne of chlorine, the three elements all unite. From
compound the hydrogen may be abstracted by
ng it with more chlorine, and a true chloride of
on results. For the minutiæ of the process we
refer to Mr. Faraday's *Memoir.* (*h.*) This sub-
e Mr. Faraday calls the *Perchloride of Carbon.*
a solid, pulverulent, or crystalline substance, having
lour something like that of camphor. Its refrac-
ower is greater than that of flint glass. Specific
ity about 2.0. It does not conduct electricity.
nelting point is 320° Fahrenheit, and it boils at
Fahrenheit. It is scarcely soluble in water, but
lves in ether or alcohol, and in both the fixed and
le oils. In the flame of a spirit-lamp it burns with
light, and supports a vivid combustion in oxygen
It is not readily affected by either Acids or
is, but the metals decompose it, abstracting its
ine. Chlorine Gas does not affect it, but iodine
ydrogen decompose it. Its composition is stated
ree atoms of chlorine + two atoms of Carbon.

)2.) By passing the vapour of the substance just
ibed over fragments of rock crystal in a red-hot
tube, a partial decomposition is effected; one
on of chlorine escapes, and a liquid *Chloride of*
on, containing one atom of each of its elements,
enses in the cooler parts of the tube. The Speci-
ravity of this fluid is 1.5526. Its refractive power
5. It is perfectly limpid, and is not combustible
, but burns in the flame of a spirit-lamp. It re-
s fluid at 0° Fahrenheit; rises in vapour between
and 170° Fahrenheit. It does not mix with
, but dissolves in ether and alcohol; is unaffected
ids or alkalis; but is decomposed at high temper-
s by oxygen, hydrogen, and the metals.

)3.) The *sub-chloride of Carbon* was brought to
and from Sweden by M. Julin of Abo, in Finland,
e it had formed accidentally during the distillation of nitric Acid from nitre and sulphate of iron. (*i.*) This substance is in the form of soft white fibres, insoluble in water; not acted upon by boiling Acids or alkalis; soluble in heated turpentine, and also in alcohol; but most of it again separates in a crystalline form as the Liquid cools. It sublimes slowly at 250° Fahrenheit; but fuses, boils, and is volatilized between 350° and 450° Fahrenheit. Potassium burns in its vapour, with deposition of the Carbon. It is decomposed by passing over fragments of rock crystal heated to redness. From the analysis of Messrs. R. Phillips and Faraday, it appears to consist of one atom chlorine + one atom Carbon.

(304.) *Chloro-carbonic Acid.* This name is now applied to a Gas called by Dr. Davy, its discoverer, *Phosgene Gas*, from the mode of its preparation. When equal volumes of chlorine and Carbonic oxide Gases are made perfectly dry and exposed in a flask for a quarter of an hour to bright sunshine, the green colour disappears and a condensation of one half the volume takes place. This Gas has a very pungent odour, reddens litmus paper, is decomposed by water into muriatic and Carbonic Acid Gases. It forms a Salt with ammonia: thus affording the rare instance of a simple base united to two acidifying principles. Its constitution is one atom Carbonic oxide + one atom of chlorine. (*k.*)

(305.) F. Unknown.

(306.) G. Undiscovered. (*l.*)

(307.) H. With the substances under this head Carbon forms most important combinations, which will for the most part be noticed hereafter. The compound of Carbon with nitrogen is called *Cyanogen.* See sect. 8. subsect. 7. Its combinations with hydrogen will be found in subsect. 3, 4, 5, 6, 7, and 8, and a curious substance formed by its union with sulphur, in sect. 6. subsect. 7.

(308.) I. With the metals Carbon forms several compounds. Those with iron are of first-rate importance in the Arts. Plumbago has been already mentioned. Steel, in all its various forms, consists essentially of iron united to Carbon.

(309.) K. The distinguishing characteristics of Carbon are, that it is solid, insipid, inodorous, fixed under ordinary processes, and (the diamond excepted) black. By combustion with oxygen it forms Carbonic Acid, a substance readily recognised.

(310.) L. The uses of Carbon are as a fuel; in the manufacture of gunpowder; as a pigment; in the formation of steel; for the production of coal Gas for the purposes of illumination; as a polishing powder. It has also a very singular power of depriving many substances of colour, and of rendering them inodorous. The principle of its action in these cases is by no means well understood. (*m.*) It is highly antiseptic, and hence it forms a good tooth-powder; it will remove the smell from tainted meat; and water may be preserved pure in long sea voyages by charring the inside of the casks. (*n.*)

Subsect. 1.—*Carbonic Oxide.*

(311.) The discovery of this Gas was made by Dr. Priestley, who obtained it from the distillation of charcoal with Oxide of zinc. Its properties were more fully developed by Mr. Cruickshank, (*o.*) and subsequently by MM. Clement and Desormes. (*p.*) The associated Dutch Chemists proposed a different view of its nature, (*q.*) which, however, has proved erroneous. It may be obtained:—

1. By distilling one part of charcoal with eight parts of Oxide of zinc in an earthen or coated glass retort. Finery cinder, which is iron in a low degree of oxidation, may be used instead of the Oxide of zinc.

2. By transmitting Carbonic Acid Gas over ignited charcoal in a porcelain tube: a convenient apparatus for the purpose is described by M. Baruel. (*r.*)

3. By distilling dry Carbonate of lime or barytes, with one-fifth its weight of charcoal, or with dry iron, or zinc filings.

The Gas so obtained must be purified by agitation with lime water, or solution of a caustic alkali.

Carbonic Oxide has an unpleasant smell: it is inflammable, burning with a blue flame. Mixed with half its volume of common air it forms an explosive compound, which may be ignited by a hot wire, or a piece of lighted charcoal. It is lighter than common air. Its action with oxygen, when in contact with spongy platinum, is described by Dr. Henry. (*s.*) This Gas is but slightly soluble in water, and does not cause any precipitate in lime water. It is noxious to animal life. (*t.*) When 100 measures of Carbonic Oxide + 50 measures of oxygen Gas are fired by electricity in Volta's eudiometer, 100 measures of pure Carbonic Acid result. Carbonic Oxide is decomposed by potassium, the metal seizing upon the oxygen and Carbon being deposited. It is also decomposed under similar circumstances by being passed through an ignited tube together with hydrogen Gas. Carbonic Oxide consists of half a volume of oxygen + one volume of gaseous Carbon condensed into one volume; or one atom of oxygen + one atom of Carbon.

Subsect. 2.—Carbonic Acid.

(312.) A. Carbonic Acid was discovered by Dr. Black in 1757. He obtained it from common limestone or magnesia, and gave to it the name of *Fixed Air.* (*u.*) He recognised also its formation during combustion, fermentation, and respiration. Carbonic Acid exists in small proportion in the atmosphere, and has been found by Saussure on the summit of Mont Blanc; also by Humboldt, in air collected by Garnerin in a balloon at the height of several thousand feet above the surface of the Earth. Vogel, however, states that a portion of air collected at sea, only two leagues from the shore at Dieppe, contained a quantity so small as to be almost inappreciable. (*v.*) Mr. Dalton estimates the quantity existing in atmospheric air at about one thousandth of the volume. Saussure, jun., on experiments made near Geneva, at 4.79 parts in 10,000, in the month of January, and at 7.18 parts on an average in the same quantity, in the months of July and August.

In old wells and similar places it is frequently generated in such quantities as to be fatal to any animal that enters such an atmosphere; it is then commonly called *Choke Damp.* It exists naturally in a curious though small cavern by the side of the Lago d'Agnano, in Italy; a district entirely volcanic; where it is mixed with sulphurous exhalations. Many mineral waters contain it in considerable quantities; such are those of Tunbridge, Carlsbad, Seltze, Pyrmont, and many others. United with lime and magnesia it forms some of the most extensive rocks of which this Earth consists. It is this substance which gives the agreeable briskness to beer, cider, champagne wines, and other fermented liquors.

(313.) B. Carbonic Acid is readily procured by putting a few small lumps of marble or chalk into a Gas bottle, and pouring upon them either sulphuric Acid diluted with six times its weight of water, or muriatic Acid, which is still better, and may be rather more diluted. The Gas disengaged may be received in jars over the mercurial trough, or even over water, though in this case some is absorbed by that Fluid. The composition of this Gas is best shown by exhibiting both its synthesis and analysis. By the combustion of a known weight of charcoal or of diamond in oxygen Gas, a quantity of Carbonic Acid Gas is generated, which may be weighed or otherwise estimated; and hence the quantity of oxygen taken into combination may be ascertained.

On the other hand, its analysis may be effected by various methods.

1. By passing a succession of electric discharges through a quantity of Carbonic Acid Gas confined over mercury, Dr. Henry found that it was decomposed into Carbonic oxide and oxygen; and when all excess of Carbonic Acid is removed, the remaining mixed Gases may be again united by the electric spark, so as to reproduce Carbonic Acid. (*w.*)

2. By heating potassium in Carbonic Acid Gas, Davy found that the metal took to itself oxygen, and that Carbon was deposited.

3. By heating phosphorus in Carbonic Acid Gas, no decomposition is produced; but Mr. Tennant found that if the vapour of phosphorus were passed over small fragments of Carbonate of lime made red-hot in a coated tube of glass, decomposition takes place; phosphoric Acid is formed, and Carbon is found as a black powder mixed with the marble. (*x.*)

From these and such processes it is ascertained that Carbonic Acid consists of two atoms of oxygen + one atom of Carbon: or, according to Gay Lussac's views, of one volume of Gaseous Carbon + one volume of oxygen, condensed into one volume.

(314.) C. Gaseous Carbonic Acid has the following properties. It instantly extinguishes flame, and is quite fatal to animal life. It is heavier than common air; having a Specific Gravity of 1.52778. It is absorbed by water, and the quantity so taken up is in proportion to the pressure employed. From such water it is again expelled by boiling, by the exhaustion of an air-pump, or by the freezing of the water. When moisture is present, it reddens vegetable blue colours. It is highly antiseptic, preventing the putrefaction of animal substances immersed in it.

Carbonic Acid has been exhibited in a liquid state by Mr. Faraday. This excellent Chemist procured it in this form by disengaging it from Carbonate of ammonia, under the violent compression of a sealed tube, one end of which was placed in a freezing mixture. The Liquid was a colourless Fluid, floating upon sulphuric Acid and water contained in the tube. It distils rapidly over at a temperature below 32° Fahrenheit. Its refractive power is much below that of water. The pressure under which this Fluid formed was found to be thirty-two atmospheres.

The action of the other elementary bodies upon Carbonic Acid has been but little examined, so that we here pass on to the principal purpose for which it is prepared. Soda water, as it is called, consists of water strongly impregnated with this Gas, and is both formed and preserved under considerable pressure, which is never removed until the bottles are opened for

It is obtained from the action of sulphuric Acid ı chalk; and sometimes a small quantity of alkali ɔeen dissolved in the water to render it more tena- ı of the Gas which it absorbs.

Compounds of Carbon and Hydrogen.

numerous and varied are the compounds of Carbon Hydrogen, which have been obtained by Chemical sses, that some Chemists have been led to suppose these two elements are capable of uniting in almost ndefinite variety of proportions. It is, however, ı more probable, that these Gases are, in fact, admixtures containing different quantities, of two ree well-defined combinations. There is also this liarity in the compounds which we are about to e; that Gases differing in properties are produced ıe very same proportionate combination of the two tituent elements. The only appreciable difference eir constitution is, however, one which we might ly suppose would produce a very marked effect the combination formed; *viz.* that the degree of ensation undergone by the Gaseous elements in case, may be double or triple of that which they r in another case, though a Gas be still the result. , if the views of Mr. Dalton be correct, one atom arbon + one atom of Hydrogen produces olefiant ; and three atoms of Carbon + three atoms of rogen produce superolefiant Gas; both the com- ds presenting only one volume of resulting Gas.

e shall here notice in succession, the various ibed compounds of Carbon and Hydrogen, gh our information concerning them is at present om being full and satisfactory; some resting on ı stronger evidence than others. They are as ws:

	Atoms or vols. of Carbon.		Atoms or vols. of Hydrogen.	Forming.
CarburettedHydrogen..	1	+	2	1 volume.
nt Gas...............	2	+	2	1 volume.
olefiant Gas (Oil Gas?)	3	+	3	1 volume.
uret of Hydrogen	6	+	3	Liquid.
uid not named (Faraday)	4	+	4	Liquid.
of Coal Tar.........	6	+	6	Liquid.
ine	1½	+	1	Solid.

ect. 3.—Light Carburetted Hydrogen. (Heavy In- mmable Air: Inflammable Air of Marshes: Hy- o-carburet: Proto-carburet of Hydrogen: Bihydro- ret of Carbon, of Thomson.)

15.) Mr. Dalton was the first to examine this Gas care, though it was known to Priestley and Cruick- ks. It may be obtained by disturbing the mud at ottom of any stagnant pond, from which it rises ıbbles through the water, and is to be collected in or bottle as usual. Thus obtained it contains t five per cent. of carbonic Acid, and rather less gen. It may also be obtained from coal Gas, of h it forms a part, by removing other Gaseous pro- ı with which it is mixed.

is Gas has neither scent nor taste; it extinguishes ing bodies, and is itself combustible, burning with ght yellow flame. It is not decomposed by being d through moderately heated tubes. Chlorine l by light decomposes this Gas, if moisture be nt: the Hydrogen unites with the chlorine to muriatic Acid; and the oxygen and carbon produce carbonic Acid or carbonic oxide, according to the proportions employed. By exposing the mixed Gases to electricity or to a red heat, hydrochloric Acid is formed and carbon deposited. (*y*.)

Fire Damp.

(316.) From the researches of Dr. Henry, it was first clearly ascertained that the *Fire Damp* of coal mines is chiefly this Gas. Its formation takes place spontaneously in the beds of coal; it then collects in cavities, and becoming mixed with atmospheric air, it forms that highly explosive compound, which lights by the approach of a candle and causes frequent melancholy accidents in mines.

Safety Lamp.

The researches made by Sir H. Davy, and the result of them, must be considered as among the most striking and beneficial applications of Chemical Science to the purposes of life. He first ascertained that when the inflammable Gas is mixed with three or four times its volume of air it is not explosive. When mixed with five or six times its volume it detonates feebly; but powerfully when the proportion is one to seven or eight: it ceases to be explosive when more than fourteen times the volume of common air is mixed with it.

With regard to the temperature at which the mixed Gases will unite, it was found that iron at even white heat was insufficient, but that any flame, however small, would cause the Gases to explode.

It had been shown by Professor Tennant, in his Lectures at Cambridge in 1814, that flame would not traverse tubes of small diameter: (*z*.) but there is no evidence to prove that Sir H. Davy's researches were directed by a knowledge of this fact, though it is not improbable that he was acquainted with it. However, proceeding in his experiments, he found that not only extremely short tubes but even a net of wire gauze was sufficient to interrupt the course of flame: and he made the admirable application of this principle to the construction of the Safety Lamp. This instrument consists of a lamp of the common construction, but entirely surrounded with a case of wire gauze. When the miner, guided by this lamp, arrives in mixed air of such quality as to be explosive, the flame of the wick at first enlarges, and should the Gas within the lamp take fire, it extinguishes the flame of the lamp and the miner must withdraw: for although no flame passes through the apertures of the gauze to ignite the Gas of the mine, yet in a short time the iron net may be destroyed by the intense heat within. Some lamps have been made with a sort of cage of platinum wire hanging over the wick. The effect of this is, that should an explosion take place within the lamp, so as to extinguish it, the platinum wire becomes sufficiently heated to continue to glow at a red heat by the silent combination that is being produced between the Gases of the explosive compound, and thus to afford the miner a feeble light for his escape. (*aa*.)

This sort of action may be elegantly exhibited by twisting a few coils of platinum wire round the wick of a spirit-lamp, so that the five or six last turns of the wire stand about one-fifth of an inch above the wick. The lamp is thus lighted, and when the wire is red-hot may be suddenly extinguished. The platinum will continue to glow for many hours in consequence of the slow combustion which it produces between the vapour of the spirit and the atmospheric air. (*bb*.)

This Gas consists of carbon one atom + Hydrogen two atoms.

Subsect. 4.—*Olefiant Gas.* (*Bicarburetted Hydrogen: Per-carburetted Hydrogen: Hydroguret of Carbon, Thomson.*)

Olefiant Gas.

(317.) The discovery of this Gas was made by the associated Dutch Chemists in 1796. They named it Olefiant Gas, from its property of forming an oil-like substance with chlorine.

To obtain it, let three measures of strong sulphuric Acid be distilled with one measure of alcohol in a glass retort by a very gentle heat. The Gas may be collected over water and freed from carbonic Acid by a solution of caustic potassa.

Olefiant Gas has a slight odour of sulphuric ether, which is formed during its production. It burns with a flame much more luminous than that of light carburetted hydrogen, and it detonates violently when mixed with oxygen in Volta's eudiometer.

When equal quantities of Olefiant Gas and chlorine are mixed together, the volume immediately diminishes and a substance is formed resembling oil in its appearance, but being more like an ether in its properties. To obtain it quite pure, it should be washed with water, and then distilled over from dry chloride of calcium. This liquid boils at 152° Fahrenheit. Its Specific Gravity at 45° Fahrenheit = 1.2201. It consists of equal volumes of the two elements, chlorine and Olefiant Gas, or of two atoms of the latter to one atom of the former. Dr. Henry proposes to call it Hydro-chloride of Carbon, which seems a very appropriate name. (*cc.*)

A compound somewhat analogous, formed of iodine and Olefiant Gas, is described by Mr. Faraday. (*dd.*) Another combination of the same substances was discovered by M. Serullas. (*ee.*)

Subsect. 5.—*Superolefiant Gas.* (*Dalton.*)

(318.) Under such respectable authority as that of Mr. Dalton and Dr. Henry, we cannot omit to mention a Gas discovered and so named by the former Chemist. We are very sensible that these compounds of carbon and hydrogen are by no means fully understood; and therefore there is the greater need to call the attention of Chemists to the point.

Mr. Dalton adduces very strong evidence of the presence of this Gas among the various products obtained by the distillation of oil and coal; but he has not as yet exhibited it in a separate form. Dr. Henry states that it must be a permanent Gas at our temperatures, and not a vapour, for he was unable to condense it by artificial cold. He considers it as composed of three volumes of the vapour of carbon and three volumes of hydrogen condensed into one volume. (*ff.*)

Subsect. 6.—*Bicarburet of Hydrogen.* (*Faraday.*)

(319.) There is an instrument called Gordon's portable Gas lamp, consisting of a cylindrical copper vessel, into which oil Gas is forced and compressed with a power equivalent to thirty atmospheres. During the process of compression a considerable quantity of Fluid is condensed, and remains a Liquid at the ordinary atmospheric pressure. As thus obtained it boils at 60° Fahrenheit; but the temperature gradually rises, and the whole is not dissipated under a temperature of 250° Fahrenheit. In consequence of the boiling point appearing more steady between 176° and 190°, Mr. Faraday carefully examined the Fluid which came over at that temperature. By various precautions he thus obtained the Fluid which he calls the Bicarburet of Hydrogen.

It is a colourless transparent Liquid, having a Specific Gravity of 0.85 at 60° Fahrenheit. It congeals at 32° Fahrenheit, and boils at 186°. It is slightly soluble in water, but readily so in fixed and volatile oils, ether, or alcohol. It burns with a bright yellow flame. Potassium does not obtain any oxygen from it. It is decomposed by passing its vapour through a red-hot porcelain tube, by which carbon is deposited and Carburetted Hydrogen escapes. According to Mr. Faraday's Analysis its constitution is six atoms of carbon + three atoms of Hydrogen.

Subsect. 7. ———— (*Faraday.*) *Quadro-carburetted Hydrogen of Thomson.*

(320.) Another combination also of carbon and hydrogen was recognised by Mr. Faraday, but he did not propose a name for it. It is obtained by heating in the hand the condensed Liquid obtained from oil Gas, and suffering the vapour thus raised to pass through tubes cooled down to zero Fahrenheit. A Liquid is thus condensed which boils upon a very slight elevation of temperature; and before the thermometer rises to 32° Fahrenheit it is wholly reconverted into vapour.

This vapour burns with a brilliant flame. At 60° Fahrenheit and bar. 29.94 it has a Specific Gravity of about 1.9065. The Specific Gravity of the Liquid is 0.627; so that it is the lightest substance known among Liquids or Solids.

It appears that this substance consists of four atoms of carbon + four atoms of Hydrogen; and that in its state of vapour eight volumes of its constituents in the Gaseous state are condensed into one volume.

Subsect. 8.—*Nafta from Coal Tar.*

(321.) During the distillation of Coal Tar, this volatile Liquid is condensed, and has received its name from its similarity to mineral Nafta. It is highly inflammable and has a strong empyreumatic odour. Dr. Thomson says that the vapour of this Liquid "requires nine times its volume of oxygen Gas to condense it completely; and when one volume of it is consumed in this way, there remain behind six volumes of Carbonic Acid Gas as a residue." He states, also, that this vapour "is not condensed by passing it through water." Thus it consists of six atoms = six volumes of carbon vapour + six atoms = six volumes of hydrogen, condensed into one volume of vapour. (*gg.*)

Subsect. 9.—*Naphthaline.*

(322.) The substance to which this name has been given was first brought into notice by Mr. Gordon in 1820. (*hh.*) It also is obtained from the nafta of coal tar by very gentle distillation. The nafta at first passes over in consequence of its greater volatility, and the Naphthaline afterwards rises in vapour and condenses upon the neck of the retort, in the form of a white crystalline Solid. Crystallized Naphthaline is rather heavier than water, has a slight and not unpleasing odour, and a nacreous appearance. It fuses at 180° Fahrenheit, and boils at 410° Fahrenheit. Naphthaline readily inflamed, but when once set on fire it freely with much smoke. It is little soluble in cold or hot water, but readily so in alcohol, olive oil, or turpentine. The alkalis do not it, but acetic and oxalic Acids dissolve it, and ink-coloured solutions. Sulphuric Acid combines it to form a new compound Acid which Mr. ay has called the Sulpho-Naphthalic Acid. (*ii.*) homson analyzed Naphthaline, and supposes it to t of an atom and a half of carbon and one atom lrogen. The properties of this substance have hiefly made known, by a very able *Memoir* on the t by Professor Kidd of Oxford. (*kk.*) We have subsection adhered to the spelling made use of by idd, but usually we have followed the spelling of , proposed by the late amiable and distinguished er Dr. E. D. Clarke. Consult also ref. (*ll.*) and the important remarks of Professor Thomson in his *Principles*, vol. i. p. 150: but it must be acknow- l that the whole of this subject requires further igation.

Gas Light.

3.) The honour of having first introduced the ets of hydrogen for common purposes of illumi- seems due to Mr. Murdoch. The Gas is ob- by heating coal or oil in iron retorts; and, if ary, the Gas evolved undergoes various processes ification before it arrives at the large gasometer, ch it is kept for the supply of the numerous and t burners wherein it is consumed. All statements o show, that the Gas thus evolved consists of a re of the several carburets of hydrogen, and that y variable proportions. As first produced, there carbonic Acid, hydrogen, sulphuretted hydrogen, me nitrogen; all which are injurious to the ulti- purpose of the manufacture. It appears quite , the goodness of Gas varies directly in propor- the quantity of those Gases present, which con- e largest proportion of carbon in their constitu- Thus, olefiant Gas, superolefiant Gas, and the rs of naphthaline, are far more serviceable for nation than the light carburet of hydrogen.

Gas from common coal is least expensive, but iires more trouble for its purification, and is by eans so luminous as the Gas from oil. The Gas canal coal is still better, in consequence of rger proportion of bituminous matter which it ns. But oil Gas is the best of all; it gives a er light, and does not require so extensive an atus for its production.

Brande made some experiments on the respec- lluminating powers of different Gases, and con- l, that to produce a light equal to that of ten andles for one hour, there were required

2600	cubic inches of	olefiant Gas.
4875	....	oil Gas.
13120	....	coal Gas.

s, however, more near the truth to consider oil as about equal in power to twice its volume of Gas. The following is an estimate of comparative se by the late Mr. Creighton of Glasgow.

ng the quantity of light given by 1 lb. of ow candles at	1*s.*	0*d.*
An equal quantity of light from sperm oil, consumed in an Argand lamp, will cost.......	0	6½
Ditto from whale oil Gas..................	0	4½
Ditto from coal Gas......................	0	2¾

For further particulars on this subject, consult reference (*nn.*), but especially the Papers of Dr. Henry, and the very able Essay by Drs. Turner and Christison.

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§ 4.—*Boron.* (*Bore*, Thenard; *Boracium*, Davy.)

(324.) A. "The saline substance called Borax has long been familiar to European artists, being employed to facilitate the fusion of the precious metals, and in the formation of artificial imitations of the precious stones. It comes from the East Indies, and is said to be found chiefly in certain lakes in Thibet and China. The word Borax occurs first in the writings of Geber, an Arabian Chemist of the Xth century. In the year 1702, Homberg, by distilling a mixture of Borax and green vitriol, obtained a peculiar substance in small white shining plates, which he called *sedative*, or *nar-*

cotic salt, and which was considered as an efficacious remedy in continued fevers. (*a.*) Lemery the younger, in the year 1727, found that this substance could be separated from Borax by the mineral Acids. (*b.*) In 1731, Geoffroy ascertained that sedative Salt gave a green colour to the flame of alcohol; and that Borax contains in it the same alkaline substance that constitutes the basis of common salt. (*c.*) In 1752, Baron demonstrated by satisfactory experiments that borax is composed of sedative salt and soda. (*d.*) Sedative salt was found to possess the properties of an Acid; it was therefore called *Boracic Acid:* but the composition of this Acid remained altogether unknown. Crell, indeed, published a set of experiments on it in the year 1800, in which he endeavoured to show, that its basis was a substance very similar to charcoal in its properties. (*e.*) But when his experiments were repeated by Sir H. Davy they did not succeed. Davy, in the year 1807, exposed a quantity of Boracic Acid to the action of the Galvanic Battery, and observed that a black matter was deposited upon the negative wire, which he considered as the basis of this Acid, but he did not prosecute the discovery further at that time. In the summer of 1808, MM. Gay Lussac and Thenard succeeded in decomposing this Acid by heating it in a copper tube with potassium. They examined the properties of its base, to which the name of *Boron* has been given, and published a detailed account of these properties. (*f.*) Davy, in 1809, decomposed the Acid by the process of the French Chemists, and published likewise an account of the properties of Boron." (*g.*)

(325.) B. "Boron may be obtained by the following process. One part of pure Boracic Acid, previously melted and reduced to powder, is to be mixed with two parts of potassium, and the mixture put into a copper or iron tube, and gradually heated till it is slightly red, and kept in that state for some minutes. At the temperature of 300° the decomposition begins, and the mixture becomes intensely red-hot, as may be perceived by making the experiment in a glass tube. When the tube is cold, the matter in it is to be washed out with water, the potash formed is to be neutralized with muriatic Acid, and the whole thrown upon a filtre. The Boron remains upon the filtre, and may be washed and dried in a moderate heat." (*h.*) Dr. Thomson, however, recommends avoiding the use of a filtre by washing the Boron in a glass vessel, repeatedly drawing off the liquid with a syphon after the Boron has been allowed to subside.

(326.) C. Boron has neither scent nor flavour; its colour is an olive brown; it is not soluble in water, ether, alcohol, or oil, even assisted by heat; it is infusible, and in close vessels remains unchanged. When first prepared it does not sink in sulphuric Acid of Specific Gravity 1.844; but after having been strongly heated it sinks rapidly through that Fluid. It is a nonconductor of Electricity. Heated in water to 176° Fahrenheit it does not decompose that Fluid.

(327.) D. At ordinary temperatures it does not undergo any change in atmospheric air or oxygen Gas; but at a temperature below 600° Fahrenheit it undergoes a rapid and vivid combustion. The process, however, is not altogether complete, for as Boracic Acid, the product of this combustion, is fusible, each globule of Boron becomes coated with the vitrified Acid, and a nucleus of the base remains unoxidized. For Boracic Acid, See subsect. 1.

(328.) E. According to Davy, when Boron is heated in chlorine Gas, the substances unite, evolving a brilliant white flame; a white sublimate condenses on the sides of the vessel in which the experiment is made, and the Boron receives a white coating, which on being washed off proved to be Boracic Acid. (*g.* p. 41.) On the other hand, Gay Lussac and Thenard state that Boron is not sensibly affected by dry chlorine Gas. (*i.*)

(329.) F. With fluorine Boron unites to form a powerful Acid, the Boro-fluoric already noticed. (191.)

(330.) G. Unexamined.

(331.) H. Sir H. Davy could not unite Boron to nitrogen, (*g.* p. 42.) nor was he more successful in his attempts upon hydrogen. Gmelin, however, effected this in the following manner. He exposed a mixture of four parts of iron filings, with one part of Boracic Acid, to a full red heat for half an hour in a crucible. The fused mass dissolved with effervescence in dilute muriatic Acid and boruretted hydrogen Gas was evolved. The Gas had the smell of common hydrogen Gas from iron, mixed with a slight smell of garlic. It burned with a reddish yellow flame, surrounded by a green border: some white fumes appearing in the vessel in which the combustion took place. (*k.*) As yet the union of Boron with carbon has not been effected.

(332.) I. Boron has been united to iron and platinum by Descotils, who heated charcoal, boracic Acid, and the metallic filings made into a paste with oil in a crucible. The compound preserved a metallic appearance. (*l.*) Gmelin made similar experiments. (*m.*) Davy found that with potassium it formed a grey metallic-looking compound. But with many other metals it seems to refuse to combine.

(333.) K. Boron decomposes nitric Acid with rapidity, nitrous Gas being evolved, and the Boron becoming boracic Acid. It also decomposes the sulphuric Acid, when aided by heat; and at a high temperature it takes oxygen from a number of the compound Salts, nitrates, sulphates, and carbonates. It reduces also several of the metallic oxides.

(334.) L. M. On these heads we have nothing to remark.

Subsect. 1.—*Boracic Acid.*

(335.) A. We have already seen (324.) that Boracic Acid was obtained in 1702 by Homberg from the decomposition of Borax, in which Salt it is found naturally combined with soda. Boracic Acid is found combined with magnesia in the mineral called Boracite found in the Kalkberg, near Lunenburg, also in the Tincal before mentioned, and in several thermal lakes in Tuscany.

(336.) B. Boracic Acid is most readily obtained by dissolving Borax in hot water, gradually adding sulphuric Acid to the filtered solution, until the Liquid becomes rather acid. A number of small shining laminary crystals gradually form and subside as the liquor cools. These are crystals of Boracic Acid, which must be well washed with clean water, and then dried between folds of blotting paper. In this state it is a hydrate: the water may be driven off by fusion, and the Boracic Acid remains pure.

(337.) C. This hydrate exhibits thin hexagonal scales with a pearly lustre; has something the appearance and feel of spermaceti; its Specific Gravity is .479, but the pure Acid after fusion is 1.803. Boracic

has no smell, but by affusion of a little Sulphuric
a musky odour is developed. Boracic Acid is not
le, but after fusion, at a red heat, it becomes on
g a hard transparent glass, which becomes opake
ally by exposure to the air, but does not de-
ce. It has the property of reddening vegetable

8.) D. E. F. G. None yet recognised.

9.) H. Neither have these substances any action
Boracic Acid; but it is soluble in alcohol, and by
d of considerable heat in oils also.

0.) I. Of the metals, potassium and sodium
have been found capable of decomposing Boracic
With regard to the action of its solution upon
s, it dissolves iron, zinc, and perhaps copper.

1.) K. Boracic Acid combines with the oxides
ry class of metals to form Salts, which are called
es.

2.) L. The presence of Boracic Acid is most
recognised by its property of colouring the flame
rning bodies green. This is easily exhibited by
mbustion of alcohol holding it in solution; but
atest method, when the quantity is small, is to dip
on thread into a Boracic solution, and then, after
the thread, to set fire to it.

3.) M. Boracic Acid is used in the fabrication of
for the imitation of precious stones; and in the
sis of minerals, which naturally contain the fixed
s. Borax, the Borate of soda, is employed in sol-
to clean the metallic surfaces, and by its fusion
vent oxidation, and thus to facilitate the union of
etallic surfaces.

References to § 4.

) *Hist. de l'Acad.* 1702, p. 50. (*b.*) *Mem. Acad.*
1728, p. 273. (*c.*) *Mém. Acad. Par.* 1732, p.
(*d.*) *Mém. Savans Etrang.* vol. ii. p. 412. (*e.*)
e Ch. vol. xxxv. p. 202. (*f.*) *Mém. d'Arcueil,*
p. 311; and *Rech. Phys. Chem.* vol. i. p. 276.
Phil. Trans. 1809. (*h.*) Thomson, *Syst.* vol. i.
2. (*i.*) *Recherches*, vol. i. p. 303. (*k.*) Gmelin,
eig. *Jour.* vol. xv. p. 246. (*l.*) *Rech. Phys. Ch.*
p. 306. (*m.*) Gmelin, Schweig. *Jour.* vol. xv.
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§ 5.—*Phosphorus.*

4.) A. Phosphorus "was accidentally discovered
andt, a Chemist of Hamburgh, in the year 1669,
s he was attempting to extract from human urine
uid capable of converting silver into gold. He
d a specimen of it to Kunkel, a German Chemist
siderable eminence, who mentioned the fact as a
of news to one Kraft, a friend of his at Dresden.
immediately repaired to Hamburgh, and pur-
d the secret from Brandt for 200 dollars, exacting
him, at the same time, a promise not to reveal it
other person. Soon after he exhibited his Phos-
s publicly in Britain and France, expecting doubt-
hat it would make his fortune. Kunkel, who had
oned to Kraft his intention of getting possession
process, being vexed at the treacherous conduct
s friend, attempted to discover it himself; and
the year 1674 he succeeded, though he only
from Brandt that urine was the substance from
Phosphorus had been procured. (*b.*) Accordingly he is always reckoned, and deservedly too, as one of the discoverers of Phosphorus."

"Boyle likewise discovered Phosphorus. Leibnitz, indeed, affirms that Kraft taught Boyle the whole process, and Kraft declared the same thing to Stahl. But surely the assertion of a dealer in secrets, and one who had deceived his own friend, on which the whole of this story is founded, cannot be put in competition with the affirmation of a man like Boyle, who was not only one of the greatest Philosophers, but likewise one of the most virtuous men of his Age; and he positively assures us that he made the discovery without being previously acquainted with the process." (*c.*) "Mr. Boyle revealed the process to his assistant, Godfrey Hankwitz, a London apothecary, who continued for many years to supply all Europe with phosphorus. Hence it was known to Chemists by the name of English Phosphorus. (*d.*) Other Chemists, indeed, had attempted to produce it but without success, (*e.*) till in 1737, a stranger appeared in Paris, and offered to make Phosphorus. The French Government granted him a reward for communicating his process. Heliot, Dufay, Geoffroy, and Duhamel saw him execute it with success; and Heliot published a very full account of it in the *Memoirs of the French Academy for* 1737." (*f.*) Thomson, *Syst.*

The process for obtaining Phosphorus was further improved by Margraf. (*g.*) Gahn first detected its presence in bones; and Scheele devised a method for obtaining it from that source.

In its pure state Phosphorus is not known to exist in nature, but its combinations are found in many animal substances, and also in some minerals.

(345.) Phosphorus is now usually obtained by calcining bones; the solid residuary matter consists for the most part of phosphate of lime. This white substance is pulverized and digested for several hours with half its weight of concentrated sulphuric Acid: but to this water is added, sufficient to reduce the mass to the consistency of cream. By this process the phosphate of lime is decomposed; sulphate and biphosphate of lime result. The latter Salt is dissolved out by boiling water, then evaporated to the consistency of sirup, mixed with one fourth its weight of powdered charcoal, and submitted to a good heat in an earthen retort. The beak of the retort should terminate in cold water; the Phosphorus is condensed by the water, and falls down in drops. Phosphorus is further purified by fusing it in hot water, and carefully pressing it through chamois leather; or else by a subsequent gentle distillation.

(346.) C. Phosphorus is generally seen of a light brown colour, but when quite pure it is nearly colourless, with a waxy appearance and fracture. It fuses at about 108° Fahrenheit, and rises fully in vapour at 550° Fahrenheit, but at 219° Fahrenheit *in vacuo.*

It may be readily cut with a knife, and has a Specific Gravity about 1.77.

(347.) D. The affinity of Phosphorus for oxygen is very considerable, and most energetic combinations take place between these substances. In atmospheric air Phosphorus undergoes a slow combustion even when no extraordinary heat has been applied, and to this cause must be attributed the luminous appearance which it exhibits in the dark. A very slight elevation of temperature, even that produced by gentle friction, is sufficient to throw it into a state of vivid combustion, during which intense light and heat are developed.

The following is a more specific summary of the mutual action of Phosphorus and oxygen given from M. Thenard, who cites the experiments of M. Bellani de Monaz. (*h.*)

1. Phosphorus placed in pure oxygen at an ordinary atmospheric pressure and temperature undergoes no change; but by diminishing the pressure, combination takes place, the Gas is absorbed, and hypophosphoric Acid is formed. And, generally, the more the pressure is diminished, the lower is the temperature at which the substances unite; but that no combination takes place below 41° Fahrenheit.

2. Further that if greater pressures are employed, a greater elevation of temperature is required to produce combination.

3. The addition of a greater or less quantity of azote or hydrogen, or carbonic Acid to a given volume of oxygen, produces with reference to the combustion of Phosphorus therein below 80°.6 Fahrenheit, the same effects as diminution of pressure. Hence the luminous appearance of Phosphorus in atmospheric air; it burns slowly, absorbing the oxygen and leaving the azote.

4. Phosphorus ought to pass into the state of vapour at ordinary temperatures by its own elastic force, in any Gas that does not act upon it Chemically. Hence if Phosphorus be allowed to vapourize in oxygen Gas, and then hydrogen, or azote, be admitted to this Gas, a luminous cloud is seen; or if, on the contrary, its vapour be formed in hydrogen, or azote, or carbonic Acid, and oxygen be admitted to this, the same effect is produced.

Whether any combination between oxygen and Phosphorus exist in such proportions as to form oxides, is a point not fully ascertained; but it is generally admitted that there are three such combinations by which distinct Acids are formed. These are the Phosphoric Acid, subsect. 1; the Phosphorous Acid, subsect. 2; and the Hypophosphorous Acid, which we shall be able here briefly to describe.

(348.) The *Hypophosphorous Acid* was discovered by M. Dulong, in 1816. Phosphuret of baryta is put into water. Phosphate of baryta is formed, and being insoluble is precipitated; to the clear filtered liquor just enough sulphuric Acid is added to remove the baryta; and the remaining solution produces, by evaporation, a viscid uncrystallizable solution of the Hypophosphorous Acid. By increased heat this Acid undergoes decomposition. (*i.*) The Salts formed by this Acid are remarkable for being all soluble and highly deliquescent. The Acid itself is supposed to contain one atom of oxygen + two atoms of Phosphorus, but with regard to the comparative proportion of the elements of all the compounds of oxygen and Phosphorus, there still seems a little uncertainty. By some this Acid has been even supposed to be an hydracid, that is to say, to contain hydrogen as a constituent element.

(349.) E. Chlorine combines with Phosphorus in two proportions. The *Protochloride of Phosphorus* (or Chloride) is best prepared by passing the vapour of Phosphorus over corrosive sublimate heated in a glass tube. Thus protochloride of mercury (calomel) is formed and the Phosphorus unites with the remaining atom of chlorine which is set free. This protochloride is a Liquid whose Specific Gravity is 1 45. It is a neutral substance not affecting vegetable colours, and contains one atom of each of its constituents.

(350.) *Deutochloride of Phosphorus* (Bichloride of some authors) is formed by placing Phosphorus in chlorine Gas; spontaneous combustion takes place, and a white solid substance forms on the sides of the retort. This substance is volatile at a temperature below 212° Fahrenheit. It acts violently on water; hydrochloric Acid and Phosphoric Acid being the results. When transmitted through a red-hot porcelain tube with oxygen Gas, the chlorine is set at liberty and Phosphoric Acid is produced, showing that at high temperatures the affinity of oxygen for Phosphorus is superior to that of chlorine for the same substance. This Deutochloride contains two atoms of chlorine + one atom of Phosphorus.

(351.) F. unexamined.

(352.) G. Iodine combines with Phosphorus at ordinary atmospheric temperatures; heat is evolved, and, as it appears from Dr. Traill's experiments, there is or is not light according to the mode in which the experiment is conducted. Two compounds are supposed to exist, but do not seem to be very tenacious of a definite state of combination. (*k.*)

(353.) H. Phosphorus combines with hydrogen in two proportions. The resulting substances are both Gaseous, and some little difficulty may occur to the student from the varied nomenclature employed by Chemists in speaking of these compounds. We shall adhere to the general rules proposed in (110.) and (111.) The *Prot-hydroguret of Phosphorus* (Phosphuretted Hydrogen of Gengembre and Kirwan; Hydroguret of Thomson) was discovered in 1783 by Gengembre, (*l.*) and independently, in 1786, by Kirwan; (*m.*) it has been further examined by Raymond, (*n.*) Dalton, (*o.*) and Thomson. (*p.*) It may be obtained by heating Phosphorus in a solution of pure potassa; or by heating a paste formed of small fragments of Phosphorus, newly slaked lime, and a little water; or by filling a small retort with water acidulated with muriatic Acid, and then adding to it a few lumps of phosphuret of lime; a very gentle heat is to be applied, and the Gas evolved must be received over water.

The Prot-hydroguret of Phosphorus has a peculiar and disagreeable odour. It is slightly soluble in water; inflames spontaneously, and burns with splendour when it comes in contact with atmospheric air or oxygen Gas. It is decomposed by a strong heat, or by the electric spark. It consists, as the name indicates, of one atom of each of its elements.

(354.) The *Deut-hydroguret of Phosphorus* (Bihydroguret of Thomson) was discovered by Davy in 1812. He procured it by heating crystallized Phosphorous Acid. The prot-hydroguret is also reduced to this state by exposure to the sun, one proportion of its Phosphorus being deposited. This Gas has a scent similar to that of the prot-hydroguret, but less strong; it does not inflame spontaneously by contact with common air or oxygen Gas, but burns with a white flame in chlorine. This Gas contains two atoms of hydrogen + one atom of Phosphorus. These two compounds might also be called sub-phosphuret and Phosphuret of hydrogen.

(355.) Phosphorus unites with carbon. This Phosphuret was first formed by Proust. Thomson gives the following as the readiest method for obtaining it:

"Allow Phosphuret of lime to remain in water till it has given out all the Phosphuretted Hydrogen Gas that it is capable of evolving. Then add to the Liquid a considerable excess of muriatic Acid, agitate for a few moments, and throw the whole upon a filter. Phosphuret of carbon will remain upon the filter. Let it be properly washed and dried."

"Phosphuret of carbon is a soft powder of a dirty lemon yellow colour, without either taste or smell. When left in the open air it very slowly imbibes moisture, emits the smell of carburetted hydrogen, and acquires an acid taste. Hence it decomposes the water which it absorbs, and its Phosphorus is slowly converted into Phosphorous Acid. It does not melt when heated, nor is it altered when kept in a temperature higher than that of boiling water. It burns below a red heat, and when heated to redness gradually gives out its Phosphorus. The charcoal remains behind in the state of a black matter, being prevented from burning by a coating of Phosphoric Acid with which it is covered. When the powder is thrown over the fire in small quantities, it burns in beautiful flakes. It is composed of one atom of Phosphorus + one atom of carbon. (*q*.)

(356.) Phosphorus combines readily with sulphur in several proportions. The Phosphuret of sulphur has a yellow colour, and possesses great tendency to crystalline structure. Its properties are not very interesting, but for those who may wish to be made acquainted with them in detail, references are given. (*r*.)

(357.) Phosphorus is soluble in nitrogen Gas, forming a Gaseous compound which has been little examined.

(358.) Alcohol, ether, and oils dissolve Phosphorus more or less, and these solutions when spread upon paper become luminous in the dark, especially in a warm atmosphere.

(359.) I. The metals are almost all capable of being united to Phosphorus.

(360.) K. Phosphorus in its pure state cannot, of course, perform the part of either an Acid or a base. The action which it possesses upon Acids and bases depends in general on its affinity for oxygen; thus it decomposes the nitric Acid to obtain a portion of its oxygen, Gaseous oxide of azote being evolved. By a similar affinity it is capable of decomposing many, if not all, the metallic oxides.

(361.) L. In its elementary state Phosphorus is easily recognised by its luminous properties, and by its ready combustibility. Its properties when acidified will be considered hereafter.

(362.) M. The immediate uses of Phosphorus are very limited, but it has served to make a small portable instrument for obtaining a light. A small quantity of Phosphorus is fused with a little lime in the bottom of a bottle: in this process it undergoes a partial oxidation, so that when a common sulphur match is introduced and again removed into the air, it inflames. Phosphorus, when administered internally, proves one of the most powerful stimulants of the animal economy, thus forming a most powerful aphrodisiac.

Subsect 1.—*Phosphoric Acid.*

(363.) A. The discovery of Phosphorus led to the immediate formation of Phosphoric Acid, which is produced by its combustion; but its true nature could not have been understood previous to the theory of acidification by oxygen. This Acid does not exist in a free state in nature, but when combined with lime it forms a principal ingredient in bones, and also a part of most animal matters.

(364.) B. Phosphoric Acid may be obtained quite pure by burning Phosphorus in oxygen Gas. White vapours are produced which condense in snowy crystals on the bottom of the retort. This solid anhydrous Acid attracts moisture from the air with great avidity, and soon becomes liquid. Phosphoric Acid may also be obtained by the action of Phosphorus on nitric Acid, but the experiment requires caution, as the decomposition takes place with violence. From Phosphoric Acid the water may be driven off by heat, and the pure Acid remains in a glassy state. Generally speaking, however, Phosphoric Acid is procured from bones by a process already adverted to. (337.) The biphosphate of lime is boiled for a few minutes with excess of carbonate of ammonia; thus carbonate of lime is precipitated, and a solution of phosphate and sulphate of ammonia remains. By evaporation, and finally by a strong heat in a platinum crucible, every thing except the Phosphoric Acid is driven off. This Acid is now for the most part supposed to consist of one atom of Phosphorus + two atoms of oxygen.

(365.) C. This Acid in its purest state is a white or transparent Solid, uniting readily with water in all proportions. M. Dulong considers that by heat alone it is impossible to expel all the water, and that what is called solid glacial Phosphoric Acid consists of three atoms of Phosphoric Acid + one atom of water. The taste is intensely sour, the effect in reddening litmus-paper is very energetic, and the Acid possesses high neutralizing powers upon the bases. This Acid is decomposed by the Voltaic pile.

(366.) D. None.

(367.) E. None.

(368.) F. Unknown.

(369.) G. Unexamined.

(370.) H. Nitrogen has no action on Phosphoric Acid. Carbon decomposes it at high temperatures.

(371.) I. Potassium and sodium decompose this Acid.

(372.) K. No other Acid is capable of employing the Phosphoric as a base; but with bases it forms numerous and important Salts. With single atoms of some bases it unites in several different proportions, forming sub-phosphites, phosphites, super-phosphites, and other classes of Salts, which we must not here enumerate. (*t*.)

(373.) L. The most marked reagent action of Phosphoric Acid is as follows. When exactly neutralized by carbonate of soda or potash, the solution undergoes no change of colour by passing a stream of sulphuretted hydrogen through it: acetate of lead produces a white precipitate, and nitrate of silver a yellow one. The former is dissolved by the addition of nitric or Phosphoric Acid, and the latter by ammonia, as well as by those Acids.

(374.) M. Phosphoric Acid is not generally employed in Medicine, but M. Lentin has recommended its exhibition in doses of twenty-five drops, to be taken in any diluent Liquid for phthisis.

Subsect 2.—*Phosphorous A·id*

(375.) N. The combustion of Phosphorus frequently produces both Phosphoric and Phosphorous Acid; but the best process for obtaining the latter substance is to pass the vapour of Phosphorus through powdered corrosive sublimate in a glass tube. Chloride of Phosphorus is formed, and condenses in a liquid form. By putting this substance into water a decomposition takes place, the hydrogen and chlorine form hydrochloric Acid, and the oxygen unites to the Phosphorus to form Phosphorous Acid. The solution must then be evaporated, so as to drive off the hydrochloric Acid, and the remaining hydrous Phosphorous Acid will on cooling assume a crystalline structure. The spontaneous oxidation of Phosphorus in atmospheric air produces the same Acid.

With bases this Acid is capable of forming Salts, but they have not been examined much in detail. It appears, however, that there exist sub, neutral, and superphosphites. Consult the *Memoir* of M. Dulong. (*u.*)

References to § 5.

(*a.*) Homberg, *Mém. Ac. Par.* vol. x. p. 84. *Phil. Trans.* 1681. (*b.*) Kunkel, *Laborator. Chemicum*, p. 660. Weigleb, *Geschichte, &c. der Chemie*, vol. i. p. 41. (*c.*) Boyle, *Works*, ed. Shaw, vol. iii. p. 174. (*d.*) Hoffman. *Obs. Phys. Chem. Select.* p. 304. (*e.*) Stahl, *Fund. Chem.* vol. ii. p. 58. (*f.*) *Mém. Acad. Par.* 1737, p. 342. (*g.*) *Miscel. Berol.* 1740, vol. vi. p. 54. *Mém. Acad. Ber.* 1746, p. 84. Margraf, *Opusc.* vol. i. p. 30. (*h.*) *Bulletin de Pharmacie*, tom. v. p. 489. (*i.*) Dulong, *Phil. Mag.* vol. xlviii. p. 271. (*k.*) Davy, *Phil. Trans.* 1814, p. 79; and Gay Lussac, *An. de Chim.* vol. xci. p. 9. (*l.*) *Mém. des Sav. Etrang.* vol. x. p. 651. (*m.*) *Phil. Trans.* 1786, p. 118. (*n.*) *An. de Chim.* vol. x. p. 19; and vol. xxxv. p. 225. (*o.*) *New Syst. Chem. Phil.* vol. ii. p. 457. (*p.*) *An. Phil.* vol. viii. p. 87. (*q.*) Thomson, *Syst.* vol. i. p. 277. (*r.*) Margraf, *Opusc.* vol. i. p. 11; Pelletier, *Jour. de Phys.* vol. xxxv. p. 382; Accum, Nich. *Jour.* vol. vi.; Briggs, Nich. *Jour.* vol. vii.; Pelletier *An. de Chim.* vol. iv. p. 10; Faraday, *Roy. Inst. Jour.* vol iv. p. 361. (*s.*) Fourcroy, *An. de Chim.* vol. xxi. p. 199. (*t.*) Berzelius, *An. de Chim. et de Phys.* vol. ii. p. 151; vol. xi. p. 114; and Mitscherlich, vol. xix. p. 350. (*u.*) *Mem. d'Arcueil*, vol. iii. p. 420.

§ 6.—*Sulphur.*

(376.) A. Sulphur is on the whole a plentiful substance, and has been known from the very earliest times. It occurs abundantly among the various products of volcanic fires, and is found also in certain mineral formations chiefly connected with clays and schists. Several of the metalliferous ores consist chiefly of this substance. When mixed with much earthy matter it is amorphous, but if its formation has taken place in cavities, or by slow processes, it presents very beautiful crystalline forms. The Island of Sicily produces it in great abundance.

(377.) B. Sulphur is obtained pure by gentle sublimation; it is then called *Flowers of Sulphur*, or *Flour of Sulphur*, but it is at first contaminated with a little sulphurous Acid, which must be removed by careful washing. Sulphur is at present considered a simple substance, though it has been difficult for some eminent Chemists to satisfy themselves that some hydrogen did not enter into its composition.

(378.) C. At our ordinary temperatures, Sulphur is a solid, brittle, and frequently crystalline substance. It fuses at about 180° or 190° Fahrenheit, and is completely fluid at 220°. It rises in vapour slightly about 170°, but becomes Gaseous at 600° Fahrenheit. If melted Sulphur be poured into hot water it remains a tenacious waxy substance, and in this state is frequently employed to take impressions of gems, coins, &c. Sulphur is a nonconductor of electricity, and becomes negatively electric by friction. It possesses high refractive power upon light.

(379.) D. When heated in atmospheric air, or oxygen Gas, Sulphur takes fire, combining with the oxygen and forming Sulphurous Acid; but by various processes four distinct combinations between Sulphur and oxygen may be produced. These will be described in subsections 1, 2, 3, and 4.

(380.) E. Chloride of Sulphur is readily formed by passing a current of chlorine through Flowers of Sulphur, or by heating Sulphur in dry chlorine Gas. This substance was first described by Professor Thomson, (*a.*) and subsequently examined by A. Berthollet, (*b.*) and by Bucholz. (*c.*) Sir H. Davy discovered another combination between the same elements. (*d.*)

The *subchloride of Sulphur* formed by Thomson's process, is described by himself "a liquid of a brownish red colour, when seen by reflected light; but yellowish green when seen by transmitted light." Its smell is strong, and somewhat similar to that of sea plants. The eyes, when exposed to it, are filled with tears. The taste is acid, hot, and bitter, affecting the throat with painful tickling. It does not change the colour of dry litmus-paper; but if the paper be moist it immediately becomes red. Specific Gravity 1.6789 or 1.7. It readily dissolves Sulphur and phosphorus, forming a permanent solution. Chloride of Sulphur smokes violently in the open air, and soon flies off, leaving crystals of Sulphur if it contains that substance in solution. When dropped into water it is decomposed, Sulphur being evolved. When dropped into nitric Acid a violent effervescence is produced, and sulphuric Acid is formed. This substance is supposed to consist of one atom of chlorine + two atoms of Sulphur.

The *chloride of Sulphur* formed by Davy's process is described as having properties similar to those of the substance just described, and Davy seems to have considered the substances identical; but Thomson supposes the latter to contain one atom of each of the elements.

(381.) F. Unknown.

(382.) G. Iodide of Sulphur was first described by Gay Lussac. (*d.*) It is supposed to contain one atom of each element; and is formed simply by heating iodine and Sulphur together in a glass tube. This compound has the appearance of sulphurate of antimony.

(383.) H. Sulphur combines with hydrogen, forming a peculiar substance formerly called sulphuretted hydrogen Gas, but now more appropriately hydro sulphuric Acid. In fact, hydrogen and Sulphur unite in two proportions. See subsect. 5.

The combination of Sulphur with carbon forms a substance of considerable interest. It was first described by MM. Clement and Desormes, (*e.*) though it had been obtained by Lampadius in 1796. (*f.*) These Chemists obtained it by adding Sulphur to charcoal contained in a porcelain tube at a red heat. This process is rather uncertain and inconvenient. The writer of this Synopsis has obtained it readily and in large quantity by fixing a tubulated porcelain retort filled with bits of charcoal into a Black's portable furnace: to the tubulure of the retort an earthen tube a foot long was luted and closed by a cork. Through this tube small fragments of Sulphur were dropped down upon the heated charcoal. The sulphuret of carbon as it formed passed off in vapour by the beak of the retort, into which a glass tube was fixed and terminated under water. Here the sulphuret was condensed in drops, and remained at the bottom of the jar of water. To obtain the Liquid in a state of purity, a subsequent distillation at a very gentle heat (110°) is required.

Bisulphuret of carbon is a limpid Liquid, of Specific Gravity about 1.27. It boils at 105° or 110°, and does not freeze at $-$ 60° Fahrenheit. It is so extremely volatile as to produce a greater degree of cold by its evaporation than any other known substance. Thus mercury may be frozen conveniently by covering the bulb of a thermometer with cotton wool moistened with this substance, and placed under the receiver of an air-pump. In the open air it takes fire at a very low temperature, and burns with a blue flame; is not soluble in water, but readily so in ether and alcohol. It is considered to consist of one atom of carbon + two atoms of Sulphur. Consult also ref. (9.)

Sulphur combines with phosphorus (356.) and selenion, but not with boron, silicon, or nitrogen.

(384.) I. Sulphur combines readily with almost all the metals, and in some cases these compounds are regulated by the laws of definite proportions.

(385.) K. Under this head there is not much to notice: by digestion with nitric Acid, Sulphur itself undergoes acidification, and is converted into Sulphuric Acid. Upon the earthy oxides Sulphur exerts no action; but at a temperature sufficiently elevated it acts upon all other oxides, in some cases reducing the metals, in others forming sulphurets.

(386.) L. Sulphur is readily recognised by its Physical properties; or, if in small quantity, it may be acidified by nitric Acid, and tested with great accuracy as Sulphuric Acid.

(387.) M. This substance is of great service in the Arts: the Sulphurous Acid produced in its combustion is used to bleach woollen substances and straw bonnets. With nitre and charcoal it forms gunpowder. It is an important ingredient in the cement used in joining iron pipes for Gas and water. In Medicine it is applied externally in cutaneous disorders. Internally, it is sometimes given in visceral obstructions, and as an alterative.

It possesses a rapid effect in counteracting the specific action of mercury on the system. For this purpose sulphuret of potash is perhaps the best form of exhibition.

Subsect 1.—*Hyposulphurous Acid.*

(388.) The Salts formed by this Acid were first noticed by M. Thenard (*h.*): its relation to the other compounds of sulphur and oxygen were then pointed out by Dr. Thomson; and lastly Mr. Herschel (*i.*) added very considerably to our knowledge of its compounds and their mode of decomposition.

Hyposulphurous Acid may be formed by passing a current of sulphurous Acid into a solution of the hydrosulphuret of lime or strontia; or by digesting sulphur in a solution of any sulphate, or by digesting iron-filings in a solution of sulphurous Acid in water. In all these cases a solution of a hyposulphite of the base remains. It appears, however, that the Acid itself cannot exist permanently in a free state; for if a hyposulphite be decomposed by sulphuric or muriatic Acid, the Hyposulphurous Acid at the moment of quitting the base resolves itself into sulphurous Acid and sulphur. Mr. Herschel did indeed obtain free Hyposulphurous Acid by adding a slight excess of sulphuric Acid to a diluted solution of the hyposulphite of strontia; but decomposition speedily took place at common temperatures, and was instantly effected by heat.

Subsect 2.—*Sulphurous Acid.*

(389.) Sulphurous Acid Gas is produced whenever sulphur is burned in common air or oxygen Gas; but it is most readily obtained by putting three parts of Sulphuric Acid and two parts of mercury into a small glass retort. The heat of an Argand lamp produces a copious evolution of the Gas, which ought to be received over mercury. Here a part of the sulphuric Acid gives up its oxygen to the metal, and is reduced to the state of Sulphurous Acid, while the remainder unites to the oxidated metal, and produces a residuum of sulphate of mercury in the retort.

This Gas has a pungent and very characteristic odour: it extinguishes combustion, and is not itself combustible. It is quite unfit for respiration. Water, especially when hot, is capable of dissolving a considerable quantity of this Gas. The bleaching properties of burnt sulphur already mentioned (387.) are due to its action; and it is singular that if litmus-paper be so bleached, the colour seems not to be absolutely destroyed, but may be again developed either by an Acid or alkali. If moisture be present, Sulphurous Acid Gas will unite with oxygen, and pass to the state of Sulphuric Acid. Nitric Acid, or oxide of manganese, produce the same effect. Of all the Gases, this one is most readily condensed into the liquid form. Mr. Faraday effected this by a pressure equivalent to two atmospheres; and M. Bussy (*k.*) produced the same effect under the ordinary atmospheric pressure by subjecting it to the cold produced by snow and salt. This Acid unites with bases, and produces Salts called sulphites. It is believed to consist of equal volumes of sulphur, vapour, and oxygen, or of sulphur one atom + oxygen two atoms

Subsect 3.—*Hyposulphuric Acid*

(390.) MM. Walter and Gay Lussac first discovered this Acid, and formed it by passing a current of sulphurous Acid Gas through water in which finely-powdered peroxide of manganese was suspended. A neutral solution of hyposulphate and sulphate of manganese is produced. The solution is to be concentrated, and then by adding an excess of pure baryta to the heated solution, and agitating it well, the oxide of manganese is separated, as also the insoluble sulphate of baryta. The filtered Liquid will contain hyposulphate of baryta and some excess of that earth in solution. This excess may be removed by a stream of carbonic Acid, and an excess of that Acid may be got rid of by boiling. The pure hyposulphate of baryta is then to be crystallized, redissolved in water, and the baryta precipitated by cautiously adding the requisite quantity of sulphuric Acid. The filtered Liquid is to be concentrated by sulphuric Acid placed in the receiver of an air-pump till it has a Specific Gravity 1.347.

This Acid is not affected by oxygen Gas, chlorine, or concentrated nitric Acid. It dissolves zinc with evolution of hydrogen Gas. It saturates bases forming Salts. Those of lime, baryta, strontia, and the protoxide of lead, are soluble, thus forming a marked distinction between themselves and the sulphates of the same bases. Hyposulphuric Acid is supposed to consist of sulphur two atoms + oxygen five atoms, (*l.*)

Subsect. 4.—*Sulphuric Acid.*

(391.) A. As far as is known, Sulphuric Acid was first obtained by Basil Valentine, in the XVth century. He procured it by the dry distillation of sulphate of iron. Subsequently it has been obtained by other processes, and is extensively employed in the Arts. It is found in combination with bases in several mineral substances, but does not exist free in nature, except possibly in small quantities among the products of active volcanoes.

(392.) B. Sulphuric Acid is now chiefly made by burning a mixture of one part of nitre with six or eight parts of sulphur in large leaden chambers, having the floor covered with a thin stratum of water. (*m.*) The Liquid thus produced consists of a solution of Sulphuric Acid in water. By subsequent evaporation the greater part of the water is driven off, and a concentrated Sulphuric Acid remains. In its highest state of concentration liquid Sulphuric Acid contains dry Sulphuric Acid one atom + water one atom.

(393.) At Nordhausen, in Thuringia, a strong liquid Sulphuric Acid is prepared from sulphate of iron by dry distillation, in earthen retorts. This Acid may be put into a glass retort, to which a large tube is attached and surrounded with ice. Ignited charcoal is placed under the retort, and the Liquid being brought to ebullition, vapours of an hydrous Sulphuric Acid pass over, and are condensed in the cold tube. This Acid, at a temperature below 77° Fahrenheit, is solid, white, and opake, at 77° it fuses and forms a Liquid, which strongly refracts light; having a density of 1.57. At a higher temperature it is volatile, so as indeed not to be easily fused, except under some pressure. This substance possesses strongly acid properties, and attracts moisture with great avidity. (*n.*) It consists of sulphur one atom + oxygen three atoms.

(394.) C. Sulphuric Acid is an oil-like fluid, and when pure is colourless. It has a very strong affinity for moisture, and produces, when mixed with water, a very considerable degree of heat. Dr. Ure states that 73 parts by weight, mixed with 27 parts of water, exhibit this property in the most striking manner. The Specific Gravity of the strongest liquid Acid is 1.850; but Dr. Ure states that if pure it is not beyond 1.8485. Mr. Dalton has given a Table exhibiting the real Acid in mixtures of Acid and water of different densities. See Part V. Table IV. Consult, also, Mr. Parke's Essay, (*o.*) and Dr. Ure's Paper. (*p.*) Liquid Sulphuric Acid may be frozen by artificial cold. In distilling over Sulphuric Acid from glass vessels there is great danger of the vessels being broken by the violent detonations with which the heated Liquid bursts into vapour; this may, however, be remedied by placing in the retort a few fragments of pounded glass, or platinum wire: the sharp points of these bodies determining the evolution of vapour in smaller bubbles, and, therefore, with less violence of effect. The nature of this action, with reference to some other curious points in the extrication of Gases, and of vapours arising during ebullition, has been examined by Gay Lussac. (*q.*) Sulphuric Acid is decomposed by the Voltaic pile.

(395.) D. None.

(396.) E. None.

(397.) F. Unknown.

(398.) G. None.

(399.) H. Of these substances not one decomposes Sulphuric Acid at common temperatures, but all with the exception of nitrogen, and possibly selenium, decompose it when aided by heat. Hydrogen effects this at a low red heat; and water, and sulphurous Acid Gas, or sulphur results. Carbon, at a high temperature, decomposes it, producing gaseous carbonic Acid, and sulphurous Acid. The action of phosphorus is analogous; and that of boron would be so in all probability.

(400.) I. Potassium and sodium decompose Sulphuric Acid with violence at all temperatures. Zinc, iron, and probably manganese, exert little action on Sulphuric Acid at common temperatures; but by the help of a moderate heat they decompose it, with evolution of hydrogen Gas, and become sulphates of the metals respectively. The hydrogen results chiefly from the decomposition of the water present, so that the process succeeds best by diluting the Acid when obtaining that Gas is the end required.

Tin, and the metals of the last three classes, do not act at all on Sulphuric Acid at ordinary temperatures; but above 212° Fahrenheit all do so except chromium, tungsten, columbium, titanium, uranium, cerium, osmium, palladium, rhodium, platinum, gold and iridium.

(401.) K. Sulphuric Acid never performs the part of a base, and its action upon other Acids is entirely of the nature of decomposition, dependent upon the elements of which they may be composed. With bases it forms numerous and important Salts, which we have not space here to enumerate.

(402.) L. Sulphuric Acid is most readily and distinctly recognised by the precipitate which it gives with borytic water, or solution of borytic Salts. The white powder so produced is insoluble in nitric Acid, but by being heated with charcoal, it is converted into a sulphuret.

(403.) M. Sulphuric Acid is largely employed in the Arts; as a lixivium in dyeing, and for dissolving indigo Sometimes, also, in tanning leather. It serves also to decompose other Salts, whose Acids are required free. In practical Chemistry, also, its uses are numerous and extensive. Vinegar is often adulterated with it; and a sort of lemonade is made with this as a cheap substitute for citric Acid.

Subsect. 5.—*Compounds of Sulphur with Hydrogen.*

In examining this part of our subject we encounter some difficulties, which chiefly arise from the confused state of our nomenclature; and in attempting briefly to dispel them, we shall be under the necessity of making a slight change in the language of some Chemists; but we trust that no confusion will thence arise, as we shall carefully present the synonymes of other authors.

Sulphur and Hydrogen unite in two proportions;—are these to be called Sulphurets of Hydrogen, or Hydrurets of Sulphur? The former was the plan at first adopted, and Berthollet, to preserve a distinction, employed the terms "*Hydrogène Sulphuré,*" and "*Soufre Hydrogené.*" The proportions are now known to be Hydrogen one atom + sulphur two atoms; and Hydrogen one atom + Sulphur one atom. The former compound unites with bases, but it has not been shown to possess acid properties; though in some sense it is probable that it does so. The latter also unites with bases, and possessing decidedly acid properties, Gay Lussac proposed to call it Hydrosulphuric Acid; thus recognising that Hydrogen is its acidifying principle, and preserving the analogy for Hydriodic, Hydrochloric Acid, &c. &c. If we consider the compound of one atom Hydrogen + two atoms Sulphur not an Acid, we may consistently with our plan call it Hydruret of Sulphur; but if we deem it an Acid, we may call it Hydrosulphurous Acid. For the second compound consisting of one atom of Hydrogen + one atom of Sulphur, we unhesitatingly adopt Gay Lussac's name of Hydrosulphuric Acid.

Hydruret of Sulpnur, or Hydrosulphurous Acid. (Soufre Hydrogèné *of Thenard; Hydrosulphurous Acid of Thomson; Bisulphuretted Hydrogen of Henry.*)

(404.) The following are the properties of this substance as detailed by Berthollet, (*s.*) and abstracted by Dr. Henry. (*t.*)

"This substance is obtained when the compound produced by boiling Flowers of Sulphur with liquid potassa is poured by little and little into muriatic Acid. A very small portion only of Gas escapes; and while the greater part of the Sulphur separates, one portion of it combines with the Hydrosulphuric Acid, assumes the appearance of an oil, and is deposited at the bottom of the vessel. Or dissolve Sulphur in a boiling solution of pure potassa; and into a phial, containing about one-third its capacity of muriatic Acid, of the Specific Gravity 1.07, pour about an equal bulk of the liquid compound. Cork the phial, and shake it; the Hydruret of Sulphur gradually settles to the bottom in the form of a brown, viscid, semifluid mass; its properties are the following.

1. "Its taste and smell resemble those of putrid eggs, but are less offensive. Its precise Specific Gravity is unknown, but it is heavier than water, and descends through it. It is inflammable, and burns in the air with a smell of Sulphurous Acid.

2. "If gently heated, Hydrosulphuric Acid Gas exhales from it, the bisulphuret loses its fluidity, and a residue is left consisting merely of Sulphur.

3. "It combines with alkalis and earths."

Its constitution has been already described.

(405.) The combinations of this substance with alkalis and earths might be called Hydrosulphurets, or Hydrosulphites, according as we deemed the substance itself an Acid or not; but unfortunately the former term has been by some applied to the true Hydrosulphates. In some Treatises the combinations now before us are called Hydroguretted Sulphurets, a term we cannot employ consistently with our plan.

The *Hydrosulphurets* then, or *Hydrosulphites*, are "formed by boiling along with a sufficient quantity of water, the alkaline or earthy base, with Flowers of Sulphur. Thus a solution of pure potassa, pure soda, or of baryta, or strontia, may be changed into a Hydrosulphuret.

"Another method of forming by a very simple process the Hydrosulphurets consists in digesting in a gentle heat a Hydrosulphate with powdered Sulphur, an additional portion of which is dissolved, while part of the Hydrosulphuric Acid Gas escapes.

"Hydrosulphurets have the following properties.

1. "They have a deep greenish yellow colour, an acrid and intensely bitter taste, and an excessively offensive smell.

2. "They deposit Sulphur when kept in close vessels, become much more transparent and lighter coloured, and less offensive to the smell.

3. "They rapidly absorb oxygen from the atmosphere and from oxygen Gas. Hence their employment in Eudiometry.

4. "On the addition of dilute Sulphuric, or Hydrochloric, or of certain other Acids, they are decomposed, Hydrosulphuric Acid Gas is evolved, and Sulphur is precipitated.

5. "When boiled in contact with filings of silver, or of copper, and of those metals only, Vauquelin found that they lose their excess of Sulphur, and become Hydrosulphates."

Hydrosulphuric Acid. (Sulphuretted Hydrogen.)

(406.) This Gas, though known before, was first examined with care by Scheele about 1777. It is frequently produced during the spontaneous decomposition of organic substances, and from the receptacles for excrementitious matters. Also as an element in numerous mineral waters, such as those of Borrages, Schinznach, Harrowgate, &c.

For Chemical purposes, it is most readily procured by heating powdered sulphuret of antimony in a retort with four or five times its weight of strong muriatic Acid. Or a protosulphuret of iron may be made by placing a mixture of two parts of iron filings and one part of sulphur in a common earthen or iron crucible, well closed, and then giving it a low red heat. The sulphuret thus formed may be pulverized when cold, and acted upon by muriatic Acid diluted with thrice its weight of water.

Hydrosulphuric Acid Gas consists of one atom of each of its elements, occupying the same volume as the hydrogen of which it is formed. This Gas is without colour, but has a very peculiar and disagreeable taste and odour, similar to that of rotten eggs. At 50° Fahrenheit it may be reduced to a Liquid by a pressure of seventeen atmospheres. It extinguishes all burning bodies, but when ignited burns with a pale blue flame. It detonates by the electric spark when mixed with oxygen. This Gas has decidedly acid properties, as it reddens litmus-paper, and may be made to neutralize alkaline bases. Chlorine and iodine decompose it, separating the sulphur and producing hydrochloric or hydriodic Acid. An atmosphere in which this Gas abounds may be purified by chlorine in a very few minutes. Hydrosulphuric Acid produces very marked effects upon metals and metallic oxides. The sulphur entering into combination tarnishes gold and silver readily. White paint is immediately discoloured for a like reason. The most delicate test of the presence of Sulphuretted Hydrogen is to paint a piece of paper with flake white, (carbonated oxide of lead.) This is instantly coloured by Hydrosulphuric Acid Gas, even when, according to Dr. Henry, only a twenty-thousandth part of the volume of air consists of this Gas. Hydrosulphuric Acid Gas is one of the most deleterious that can be respired. Dupuytren and Thenard found that air containing 1-1500th part instantly destroyed a small bird; 1-800th killed a dog; and 1-150th destroyed a horse. (*r.*)

(407.) The *hydrosulphates,* as the name implies, consist of combinations of Hydrosulphuric Acid (sulphuretted hydrogen) with bases.

This Acid combines with bases from the second class of metals, and, perhaps, also with glycynea and ythria; with oxide of zinc, with the protoxides of manganese and iron, the oxides of tin, and the protoxide of antimony. With the oxides of the last four classes, no such union is formed, for the oxides themselves are decomposed and sulphurets produced. The alkaline and earthy hydrosulphates are soluble in water, are colourless, and have a sharp and rough taste. The rest, which are insoluble, have neither scent nor taste; and three only, *viz.* those of iron, antimony, and tin, are coloured. All Acids except the carbonic decompose the hydrosulphates, by setting the Acid Gas free.

The hydrosulphates of potash, soda, barytes, strontia, lime, and magnesia are prepared by passing a current of the Gas through these substances dissolved or suspended in water by means of a Woulfe's bottle. The insoluble hydrosulphates are obtained by double decomposition.

The great and constant utility of the hydrosulphates as tests of metallic substances, will induce us to give a table of these indications. See Part V. Table V.

(408.) On the whole then it appears, that sulphur, Hydrosulphurous Acid, (hydroguret of sulphur, of some,) and Hydrosulphuric Acid (sulphuretted hydrogen of some) will all unite with metals and their oxides. In the first case, the result is a sulphuret; in the second, it is a hydrosulphite, or, as we might call it, a Hydrosulphuret; (hydrogurretted sulphuret of some;) and in the last it is a hydrosulphate (hydrosulphuret of some.) The sulphurets can only continue stable in a dry state, for so soon as they begin to dissolve in water, that Fluid is decomposed, Hydrosulphuric Acid Gas is formed and evolved, while Hydrosulphurous Acid being also formed unites with the base. (*t.*)

References to § 6.

(*a.*) Nich. *Jour.* vol. ii. p. 102. (*b.*) *Mém. d'Arcueil,* vol. i. p. 161. (*c.*) Gehlen's *Jour.* vol. ix. p. 172; *Elements,* p. 280. (*d.*) *An. de Ch.* vol. xci. p. 22. (*e.*) *An. de Ch.* vol. xlii. p. 136. (*f.*) Crell's *Annals,* vol. ii. p. 136; and Gehlen's *Jour.* vol. ii. p. 192. (*g.*) Berthollet, *Mém. d'Arcueil,* vol. i. p. 304; Cluzel, *An. de Ch.* vol. lxxxiv. pp. 72. 113; Thenard, &c. *An. de Ch.* vol. lxxxiii. p. 252; Berzelius and Morcet, *Phil. Trans.* 1813, p. 171. (*h.*) *An. de Ch.* vol. lxxxv. (*i.*) *Edin. Phil. Jour.* vol. i. pp. 8. 386. (*k.*) *An. Phil.* N. S. vol. viii. p. 307. (*l.*) *An. de Ch. et de Phys.* vol. x. p 312. (*m.*) Parke, *Chemical Essays,* vol. ii. (*n.*) Bussy, *An. de Ch. et de Phys.* vol. xxvi. p. 411. (*o.*) *Essays,* vol. ii. p. 461. (*p.*) *Jour. of Science,* vol. iv. p. 127. (*q.*) *Ency. Met.* Art. *Heat,* (74.) (*r.*) Rouelle Macquire, *Chem. Dict.* vol. i. p. 520; Scheele, *On Air and Fire,* p. 186; Bergman, *Opusc.* vol. i. p. 233; Kirwan, *Phil. Trans.* 1786, p. 118; Van Troostwyck, &c. *An. de Ch.* vol. xiv. p. 294; Berthollet, *An. de Ch.* vol. xxv. p. 233; Berselius, *Afhandl.* vol. ii. p. 78; Gay Lussac, &c. *Recherches, P. C.* vol. i. p. 191; Davy, *Phil. Trans.* 1812, p. 412; Faraday, *Phil. Trans.* 1823, p. 192; Thomson, *First Principles,* vol. i. p. 217. (*s.*) *An. de Ch.* vol. xxv. p 247. (*t.*) *Elements,* vol. i. p. 446; *An. de Ch.* vol. xxv. p. 247, &c.; *An. de Ch. et de Ph.* vol vi. p. 322.

§ 7.—*Selenion.*

(409.) A. Messrs. Gahn, Eggertz, and Berzelius are the proprietors of a manufactory of sulphuric Acid from the sulphur obtained in the copper-mine of Fahlun, in Sweden. In examining, in 1817, the brown residuum or sediment on the floor of a leaden chamber in which the sulphur is burned, Berzelius found that this substance, besides containing sulphur and other impurities, consisted in part of a peculiar substance, which proved to be a simple body heretofore unknown. He considers it a metal, and named it *Selenium,* from σελήνη, the moon, in consequence of its properties greatly resembling those of tellurium. In describing these properties, we are inclined to think that many will agree with us in removing it from the rank of a metal, and placing it among the combustible nonmetallic elements, in which we follow the plan of Thomson and Thenard. Selenion has hitherto been found principally in two minerals, the seleniuret of copper, and eukairite, a seleniuret of silver and copper, discovered by M. Berzelius in the abandoned copper-mine at Skrickerum, in the parish of Tryserum, in Smoland. The pyrites of Fahlun also contain it, and it has subsequently been recognised with sulphur in the volcanic districts of Italy.

(410.) B. The residuary powder which contains the Selenion has also an admixture of several other substances; *viz.* sulphur, mercury, lead, tin, iron, copper, zinc, and arsenic. For the complete process of separation, which is very complex, we must refer to the original *Memoir* of Berzelius. (*a.*) The following are its principal features. The reddish brown powder is digested in nitro-muriatic Acid to acidify the Selenion. Water is then to be copiously added, and the Liquid filtered. To this clear solution, which contains the Selenic Acid, together with some other substances, a solution of muriate of ammonia is then added in excess, by which the Selenion is thrown down pure in a pulverulent state, and is to be well washed with water, then dried and carefully fused.

(411.) C. Selenion is at ordinary temperatures a solid, tasteless, and scentless substance, of a deep chocolate brown colour with a sort of metallic lustre. It is brittle, has a conchoidal fracture producing a lead-coloured surface. The powder is of a deep red colour, and thin fragments transmit the red rays of light. It may be scratched with a knife. Selenion does not readily crystallize, but the forms it is supposed to assume are those of a cube, and a quadrangular prism with a pyramidal summit.

It is a very bad conductor of heat, and is a nonconductor of electricity, which seems a strong argument against its being a metal; and yet, on the other hand, Berzelius was not able to produce electric excitement in it by friction. Upon being heated Selenion softens; at 212° it becomes semifluid, and is quite liquid at 230° Fahrenheit. It may be kneaded between the fingers and drawn out into threads like sealing-wax. Filaments so produced are red by transmitted light, and their reflected light is grey. In a retort, Selenion boils at a heat below redness, and its vapour is a yellow, deeper in colour than chlorine Gas, but not so deep as the vapour of sulphur. This vapour condenses in the neck of the retort in black drops, similar to those produced in the distillation of mercury. But when this substance is heated in large vessels, or in the open air, the condensed vapour actually becomes a fine powder of its appropriate red colour: a formation analogous to the Flowers of sulphur. Selenion when heated dissolves in the fat oils, in lard, and in wax, but is not soluble in the essential oils.

(412.) D. Selenion has no action on oxygen Gas without the aid of heat; but by the help of that agent it may be made to combine with oxygen in two proportions. Fill a balloon with oxygen Gas, and put into it a small piece of Selenion, allowing the balloon to communicate with a gasometer of oxygen Gas by a tube. Then apply a gentle heat to the matrass. If the balloon be only about an inch in diameter, the Selenion will inflame the moment it enters into ebullition, and will burn with a feeble flame, white at its base, and greenish at its apex. By this combustion *Selenic Acid* is produced, which sublimes and is condensed in a white powder, while the Selenion totally disappears. Vide subsect. 1.

But if this experiment be made in a large balloon holding some pints, the Selenion does not take fire, but unites all at once with the oxygen; and in this case, instead of the Acid there is an oxide of Selenion formed which is Gaseous, and has the smell of decayed cabbage, or horse-radish. Berzelius attributes this variety of action to the pressure existing in the small vessel, which does not suffer the dispersion and volatilization of the oxide as in the more roomy one. The Gaseous oxide of Selenion is colourless; does not affect vegetable colours; is very slightly absorbable by water, but communicates to it its own peculiar odour; does not unite with alkalis. Berzelius thinks that it can only exist as a Gas.

(413.) E. Berzelius placed Selenion in a glass tube, and passed a current of chlorine through the tube as long as the Selenion continued to absorb any of the Gas. The chloride so formed was at first a Liquid, but gradually became a white Solid, as it approached the point of saturation. It contracts slightly by heat but does not melt, and then sublimes in the form of a yellow vapour, condensing on any cool part of the apparatus in small white crystals. It dissolves in water with slight effervescence, and the selenic and hydrochloric Acids are found mixed with the water.

(414.) F. G. Unexamined.

(415.) H. Selenion has been combined with hydrogen, phosphorus, and sulphur. By the first *hydroselenic Acid* is produced. See subsect. 2. By dropping Selenion into melted phosphorus it rapidly dissolves, forming at the same time a compound which sinks in red streaks passing through the phosphorus. But these two substances will unite in any proportion by fusion. Berzelius, however, supposed that he obtained a definite phosphuret of Selenium, and he found that by digesting this phosphuret in water the water was decomposed, hydroselenic Acid Gas was evolved, and some Selenium precipitated.

Sulphuret of Selenium is formed by passing hydrosulphuric Acid Gas through an aqueous solution of selenic Acid. The Liquid becomes turbid and yellow; and the addition of a little hydrochloric Acid causes the sulphuret of Selenion to fall down as a deep orange-coloured powder. This sulphuret softens at 212° Fahrenheit, and liquefies by a few degrees further accession of temperature. It may be boiled and distilled over. The portion so distilled is transparent, of a reddish orange colour, resembling melted orpiment. It is not acidifiable by nitric Acid, but is more powerfully affected by the nitro-muriatic. It is soluble in caustic fixed alkalis, and in the hydrosulphurets, but again precipitable by Acids as a sulphuret of Selenion.

The relations of Selenion with carbon, boron, and silicon have not been investigated; but with the first of these substances Berzelius thinks it may form a substance analogous to the sulphuret of carbon.

(416.) I. We are at present acquainted with fifteen metallic seleniurets, and for this knowledge we are indebted to Berzelius. These seleniurets are of potassium, zinc, iron, tin, arsenic, antimony, cobalt, bismuth, copper, lead, telurium, mercury, silver, palladium, and platinum; and it is probable that this substance will be found to unite with all other metals on trial.

The metallic seleniurets seem to be subject to the same Chemical laws with the metallic sulphurets. They are similarly affected by air, water, oxygen Gas, and by changes of temperature. They are also definite compounds, and, as in the case of the sulphurets, it seems probable that there exists more than one definite compound to each metal.

The best process for obtaining the seleniurets as definite compounds is to precipitate their metallic solutions by hydroselenic Acid. By this method the deuto-seleniurets are formed. To obtain the proto-seleniurets we must heat the metals in contact with Selenion, and then drive off the excess of the latter by heat.

(417.) K. The nitric and hydrochloric Acids, when cold, do not act upon Selenion, but with the aid of heat they rapidly convert it into selenic Acid.

(418.) L. Selenion is most easily recognised by the very disagreeable odour of decayed horse-radish which a very minute quantity produces when placed in the exterior flame of the blowpipe.

(419.) M. The rarity of Selenion would preclude its application to the Arts, even if it were found serviceable. Its Medicinal properties are unknown; but the fumes of hydroselenic Acid inhaled appear to be extremely pernicious, and Berzelius thinks that a very small quantity would prove fatal to animal life.

Subsect. 1.—*Selenic Acid.*

(420.) A. B. This Acid was discovered by Berzelius, and one method of obtaining it has been already described; (412.) but in practice it is found more convenient to add one part of selenion to three or four parts of pure nitric Acid. The mixture is gradually raised to ebullition, and at that temperature the selenion rapidly decomposes the nitric Acid, seizing on a part of its oxygen. When all the selenion is dissolved, it is entirely acidified: the solution is to be evaporated to dryness in a porcelain capsule, and is then pure Selenic Acid. But if the solution be only concentrated and not evaporated, the Selenic Acid will, upon cooling, crystallize in six-sided prisms. By a considerable increase of heat this Acid parts with water, and lastly rises in a yellow vapour. This vapour condenses on the upper part of the apparatus in long, slender, tetrahedral prisms.

(421.) C. Selenic Acid has no scent, but a strongly acid taste, and reddens vegetable blues. It is volatilized but not decomposed by heat. It attracts some moisture from the air, but does not actually deliquesce. It is very soluble in cold water, and still more so in hot water. Alcohol also dissolves it readily. Hot water, which has been saturated with it, lets fall the Acid in small crystals, if rapidly cooled, but in striated prisms when slowly so.

(422.) D. None.

(423.) E. Selenic Acid is capable of absorbing chlorine. The compound so formed is capable of decomposing water, and upon this decomposition hydrochloric and Selenic Acids are found in the solution.

(424.) F. G. Unexamined.

(425.) H. Thenard says, " It is probable that with the aid of heat, hydrogen, boron, carbon, and phosphorus would decompose the Selenic Acid."

(426.) I. The same able Chemist considers it certain that the metals of the first four classes will decompose Selenic Acid at a high temperature, and states that if the Acid be dissolved in water, and then a little hydrochloric Acid be added to the solution, a plate of zinc or iron will precipitate the selenion in red, brown, or dark-grey flocculi.

(427.) K. Selenic Acid, in any solution, is easily decomposed by rendering the solution slightly acid, and then adding sulphite of ammonia. The sulphurous Acid takes the oxygen and becomes sulphuric Acid, and the selenion falls down as a dark powder. The strong fixed Acids drive off Selenic Acid from bases with which it may be combined.

The Selenic Acid unites with bases in more proportions than one; but for these Salts we must refer the reader to the *Memoirs* of Berzelius, or to Thenard, *Traitè de Chimie*, art. 877. Bis.

(428.) L. The nitrates of silver and lead are the most marked tests of Selenic Acid

Subsect. 2.—*Hydroselenic Acid.*

(429.) A. Hydroselenic Acid is, as the name implies, an Acid compounded of hydrogen and selenion, analogous to the hydrosulphuric, hydriodic, hydrochloric, &c. For the knowledge of this proximate element we have still to refer to the experiments of Berzelius.

(430.) B. The best process for obtaining this Acid in the Gaseous state is to act upon the seleniuret of iron with hydrochloric Acid in a glass proof or small retort; but as the Gas is soluble in water, it must be collected over mercury. In this process, water is decomposed, protoxide of iron is formed, which combines with the hydrochloric Acid, and Gaseous Hydroselenic Acid is evolved. M. Thenard, however, states that in this process another Gas is also formed, which is neither soluble in water nor in alkalis, and that, therefore, to obtain the Hydroselenic Acid quite pure, it might be advisable to employ the seleniuret of potassium.

(431.) C. This Gas is colourless, and reddens the tincture of turnsole. Its odour, which at first resembles that of hydrosulphuric Acid Gas, shortly changes to a sharp astringent sensation, not entirely devoid of pain. The eyes become red and inflamed, and all sense of smell is for a time destroyed. A bubble the size of a small pea is sufficient to produce these effects. So at least M. Berzelius found, to such an extent, that he was able to apply the strongest solution of ammonia under his nose, and did not recover any power of sensation in it until five or six hours had elapsed. At the same time a very copious defluxion from the mucous membrane of the nostrils came on and continued fifteen days. Similar, though less violent, effects took place on subsequent occasions, when bubbles no larger than a pin's head escaped accidentally, and became mingled with the atmospheric air. These were not all the ills that resulted from breathing this noxious Gas; for even in this mitigated form M. Berzelius perceived the approach of a dry fixed cough, which came on in half an hour, remained a long time, and finally was accompanied by an expectoration, giving a taste precisely like that of the vapours of a boiling solution of corrosive sublimate, and did not depart until he had applied a blister to his chest. In short, this admirable Chemist considers this the most noxious Gas at present known. Water absorbs a greater proportion of this Gas than of the hydrosulphuric Acid; but even when it holds half its volume in solution, the water has acquired but little smell. The Liquid so formed causes an indelible brown mark on the human skin, and is itself colourless if the water be quite free from air; but if left exposed, the Hydroselenic Acid is decomposed, and the Liquid becomes turbid from the flocculi of selenion that present themselves. Hence it is apparent why a solution of this sort becomes turbid next to the exposed surface first.

(432.) D. E. F. G. H. I. Imperfectly known.

(433.) K. Nitric Acid, when added in small quantity to the aqueous solution of Hydroselenic Acid, produces no effects.

(434.) L. The aqueous solution of Hydroselenic Acid causes precipitates in almost all the metallic solutions of the four last classes. These precipitates are for the most part black or brown, and take a brilliant metallic lustre by friction with polished hæmatites. Those, however, of zinc, manganese, and cerium are to be excepted; they are flesh-coloured, and are supposed to be hydroseleniurets of the oxides, while the others are metallic seleniurets. Consequently Hydroselenic Acid will for the most part decompose the oxides of the last four classes, even when united with the strongest Acids.

References to § 7.

(*a.*) Berzelius, *An. de Ch. et Ph.* vol. ix. pp. 160. 225. 337., or *An. Phil.* June, August, October, December, 1819, and June, 1820; Rose, *An. de Ch. et Ph.* vol. xxix. p. 113.

§ 8.—*Nitrogen.*

(435.) A. This Gas was first discovered in 1772 by Professor Rutherford of Edinburgh. Scheele also had made himself acquainted with it previous to 1777. Nitrogen forms a very considerable proportion of the atmosphere in which we exist. Lavoisier called it azote, from its not having the power of supporting animal life.

(436.) B. There are several methods employed for procuring Nitrogen Gas.

1. Let equal weights of iron-filings and sulphur be made into a paste with water, and let the vessel containing this paste be placed on a stand over the pneumatic trough. Invert over it a jar of common air, and let it stand for a day or two. One-fifth of the volume of the air will disappear, and the remainder is Nitrogen Gas.

2. Phosphorus burned in a close vessel of atmospheric air over water removes the oxygen and leaves the Nitrogen. The residual Gas should be well agitated with water to remove the phosphoric Acid formed.

3. Nitrogen may also be obtained by putting some lean beef into a glass proof with very dilute nitric Acid. A heat of about 1000° disengages the Gas, which must be collected over water.

4. But perhaps the most speedy way of obtaining it is to pass nitrous Gas copiously through a solution of protosulphate of iron. An ounce or two of this solution is then to be put into a phial, which must be closely corked or stopped with the thumb and well shaken; the phial is then to be inverted with its neck in another portion of the solution and unstopped, a fresh portion of the Liquid will enter to supply the absorption that has taken place. By a few repetitions of this process all the oxygen Gas will be removed, and pure Nitrogen will remain.

(437.) It has been supposed by very able Chemists, Davy and Berzelius especially, that Nitrogen is a compound body. Berzelius thus reasons on theoretical grounds chiefly: and Davy from a very curious experiment made with the Voltaic pile. Let a small hole be made in the surface of a lamp of muriate of ammonia, and in this hole place a globule of mercury. Connect the saline mass with the positive pole of the battery and the mercury with the negative pole; an action is immediately perceived in the metallic globule, its volume becomes enlarged, and more solid ramifications are perceptible in the fluid metal. This enlargement sometimes extends to ten times the original volume of the mercury. When completed, the amalgam (if such it be) is of the consistency of butter. It soon, however, returns to its original state by the formation of films of saline matter over its whole surface. The best experimentalists, however, could only obtain mercury, hydrogen, and azote from the amalgam so formed. (*a.*)

(438.) D. In speaking of Nitrogen with reference to oxygen, we are first called upon to mention the great mass of our atmosphere, which consists almost entirely of these two Gases: but from the importance of this agent we shall consider its properties apart in subsect. 1.

When Nitrogen and oxygen are mixed together, no combination takes place. But when either of the elements is presented to the other in a state of condensation, or having the repulsive force of its molecules diminished by a decrease of heat, a union is effected, and the nature of the resulting compound is dependent upon the respective proportions of the two elements. Some of these combinations are always Gaseous, others, though in themselves Gaseous also, are always seen in combination with so much of the elements of water as to be Liquids.

The following is a synoptic view of the compounds of Nitrogen and oxygen:

	Atoms or volumes.			Weights.		
	Nitrogen.		Oxygen.	Nitrogen.		Oxygen.
Nitrous oxide......	1	+	1	14	+	8
Nitric oxide......	1	+	2	14	+	16
Hyponitrous Acid..	1	+	3	14	+	24
Nitrous Acid......	1	+	4	14	+	32
Nitric Acid........	1	+	5	14	+	40

These substances will be noticed in subsects. 2, 3, 4, 5, and 6.

(439.) E. Chlorine and Nitrogen, when placed in contact, have no mutual action on each other, provided that both Gases are perfectly dry. A compound of these Gases may, however, be produced by passing a current of chlorine Gas through a solution of any ammoniacal Salt. The most convenient process for forming the chloride of Nitrogen, (to which the name of Azotane has been sometimes given,) is to fill a clean glass basin with a solution of muriate or nitrate of ammonia, containing about one part of the Salt dissolved in twelve parts of water, at 80° or 90° Fahrenheit. Over this solution let a tall jar of chlorine Gas be inverted. The Gas is gradually absorbed, and a film of an oil-like substance forms on the surface of the Liquid, and when a drop of sufficient size is collected, it sinks down to the bottom of the basin. The best way of removing a globule of this chloride of Nitrogen for any purpose of examination, is by a syringe made of a piece of glass tube, with a piston of tow wrapped round a wire.

Scarcely any known substance requires such care in its management as this Fluid, for it is the most violently detonating body known. It is not safe to make experiments on more than a single small globule not larger than a grain of mustard seed. M. Dulong, who discovered it, received a severe injury on the occasion; (*b.*) and Sir H. Davy did not fare better in repeating Dulong's experiments. (*c.*) A heat something below 212° Fahrenheit causes it to explode; also the contact of oil, phosphorus, and numerous other bodies; but the metals, alcohol, resins, sugar, or camphor, do not cause its explosion. Its Specific Gravity = 1.653, and it is supposed to contain Nitrogen one atom + chlorine four atoms. (*d.*)

(440.) F. Unknown.

(441.) G. Iodine and Nitrogen do not unite by mere contact; but when iodine is placed in a solution of ammonia in water, a brownish black iodide of Nitrogen is formed. This compound, like the chloride of Nitrogen, evaporates spontaneously in the open air, and detonates violently when heated or touched.

(442.) Of these substances, hydrogen and carbon unite with Nitrogen, the former producing *ammonia*, see subsect. 7; the latter producing *cyanogen*, see subsect. 8.

(443.) I. Of the metals it would seem that potassium and sodium may be considered as uniting in some manner with Nitrogen.

(444.) K. None.

(445.) L. Nitrogen is best recognised by its negative properties when in the Gaseous state: that it is not combustible, nor does it support combustion.

(446.) M. None.

Subsect 1.—The Atmosphere.

(447.) "The Atmosphere is a collection of elastic Fluids, retained on the surface of the Earth by their gravitation. Its weight was first ascertained by Galileo, and applied by Toricelli to explain the rise of water in pumps, and of mercury in barometrical tubes; and by Pascal to the mensuration of the heights of mountains. At the level of the Ocean it is adequate to sustain a column of water having the altitude of 34 feet, or one of mercury of the height of 30 inches, and it presses with the weight of about 15 pounds on every square inch of surface. As we ascend, the Atmosphere decreases in density in a Geometrical proportion to equal ascents. Thus, at three miles in height, the density of the Atmosphere is one-half what it is at the Earth's surface, or equal to a column of 15 inches of mercury; at six miles, the barometer would stand at one-fourth the usual height, or at 7½ inches; at nine miles of elevation, at 3¾ inches; and at 15 miles nearly at one inch. Hence the greatest part of the Atmosphere is always within 15 or 20 miles of the Earth's surface; though from the refraction of the Sun's light, it may be inferred to extend from 40 to 45 miles in height. Beyond the former limit it appears highly probable, indeed, from the recent observations of Dr. Wollaston, (*Phil. Trans.* 1822,) that our Atmosphere does not reach at all; the force of Gravity downwards, upon a single particle, being there equal to the resistance arising from the repulsive force of the medium. We have no evidence, then, of the existence of similar matter round any other Planet; and, on the contrary, it has been ascertained by the observations of Captain Kater, that no retardation of the motion of Venus can be perceived in her progress towards the Sun, as would happen if the latter were encompassed by a refracting Atmosphere. The approach, also, of Jupiter's Satellites to the body of that Planet is uniformly regular, till they appear in actual contact, showing that there is not that extent of Atmosphere, which Jupiter should attract to himself from an infinitely divisible medium filling all space. These observations are favourable, as Dr. Wollaston remarks, to the existence of particles of matter no longer divisible, for if an elastic Fluid like our Atmosphere consist of such particles, we can scarcely doubt that all other bodies are similarly constituted; and may, without hesitation, conclude that those equivalent quantities, which we have learned to appreciate by proportional numbers, do really express the relative weights of elementary atoms, the ultimate objects of Chemical research.

"The great body of air constituting our Atmosphere is in a state of constant motion, not only from its accompanying the Earth in its rotation round its axis, but it flows also from the Equator towards the Poles, and contrariwise. Over the torrid zones the air is expanded by heat, and acquires a tendency to ascend, while the air from the temperate and frigid zones presses forward to supply the vacancy. In the torrid zones, the upper regions of the Atmosphere meet with less lateral pressure than is necessary to support them, and the air, therefore, overflows in both directions, so that currents Northward and Southward are established for supporting a temperature on the Earth's surface, approaching much more nearly to uniformity, than it could have been without such a provision of nature." Henry, *Chemistry*, vol. i. p 287.

(448.) We may state in general terms that the mass of the Atmosphere consists of

	By weight.	By measure.
Nitrogen Gas	77.50	75.55
Oxygen Gas	21.00	23.32
Aqueous vapour....	1.42	1.03
Carbonic Acid	0.08	0.10
	100.	100.

A small quantity of muriatic Acid is found in the air which is in contact with the sea; and the aqueous vapour is of course variable according to the temperature; but in other respects, a most singular and striking uniformity of composition has been found to pervade all the air hitherto examined, whatsoever may have been the altitude from which it has been taken.

A pressure of 30 inches of mercury is supported by the ingredients already named in the following proportion, supposing each to act independently of the others.

Nitrogen Gas......	23.36	inches.
Oxygen Gas	6.18	ditto.
Aqueous Vapour ...	0.44	ditto.
Carbonic Acid Gas .	0.02	ditto.

Two opinions exist as to the mode in which these Gases exist together in the Atmosphere. The one that they are all in Chemical combination with each other; and the other opinion is, that no such combination takes place, but that the Atmosphere is merely a mechanical mixture of its ingredients. The latter opinion is ably supported by Mr. Dalton. (*d.*)

It is owing to the oxygen Gas in the Atmosphere, that it supports respiration and combustion. When rarefied, the air does not so readily afford the food that is necessary for burning bodies; and this seems to depend upon a want of condensation of that heat which is requisite for keeping up the combustion. Though it appears from Davy's experiments, that artificial condensation does not render it better fitted for that purpose.

(449.) The weight of 100 cubic inches of Atmospheric air at thermometer 60° Fahrenheit, and barometer 30 in. was said by Mr. Kirwan to be 30.92 grains troy. Sir H. Davy states it at 55° Fahrenheit, 31.10 grains. Sir George Shuckburgh at 30.5 grains, which is the estimate generally admitted. But Mr. Brande obtained by experiment 30.199 grains. Dr. Prout, whose accuracy and caution give his opinions a very great weight, is disposed to think that even Sir G. Shuckburgh's estimate is below the truth; and from him, if from any one living, we may look for a full and satisfactory investigation of this most important element in many of our calculations.

(450.) The determination of the quantity of oxygen Gas existing in a given portion of Atmospheric air, was early considered to be the same thing as ascertaining the purity of the air for respiration, &c.; and hence it obtained the name of *Eudiometry*. (εὐ διὸς μέτρον.)

Lavoisier exposed a quantity of mercury to heat in a retort which communicated with a jar of Atmospheric air; it will be obvious that the oxygen was removed, and the residuary Gas was nitrogen.

Berthollet employed a cylinder of phosphorus exposed to a known quantity of Atmospheric air confined in a tube over water. By the slow combustion of the phosphorus the oxygen was abstracted. A vapour of phosphorus, however, remains, forming the $\frac{1}{21}$st part of the residuary Gas, for which allowance may be made. (*e.*) Seguin adopted the rapid combustion of phosphorus on similar principles. Several eudiometrical instruments have been constructed for the purpose of exposing a given volume of Atmospheric air to any liquid capable of absorbing and removing its oxygen. Such are Guyton's, (*f.*) Hope's, (*g.*) Henry's, (*h.*) and Pepy's eudiometer. (*i.*) The Liquid employed is either sulphuret of potash, sulphuret of lime, or a solution of sulphate of iron, saturated with nitrous Gas. But of all eudiometers that of Volta is, perhaps, the most satisfactory. It, with other instruments of the same sort, is described in our introductory Chapter on Apparatus.

calls the Acid *water of nitre*. It was afterwards denominated *aqua fortis*, and *spirit of nitre*. The name *nitric Acid* was first given it in 1787 by the French Chemists." (Thomson.)

The direct synthetic formation of nitric Acid was first produced by Mr. Cavendish. It consists in passing a continuous current of electric sparks through a mixture of nitrogen and oxygen Gases. (*t*.) This Acid is, however, manufactured by distilling a mixture of sulphuric Acid and nitre. The Gaseous product is conducted into a vessel containing water, which being absorbed produces liquid nitric Acid. (*u*.) Nitric Acid Gas consists of five atoms of oxygen + one atom of nitrogen, but the strongest liquid Acid that can be obtained consists of the Acid Gas one atom + water one atom. It is frequently a matter of great convenience to know the quantity of real Acid contained in solutions of given density. We have, therefore, inserted Table VI. in Part V. by Dr. Ure, as the most extensive with which we are acquainted for that purpose. The Acid which Professor Thomson supposes to contain one atom of water to one atom of dry Nitric Acid Gas should have a Specific Gravity = 1.55, but that which he obtained equalled only 1.534. The Table, however, deduced from his experiments (*v*.) will be found Part V. No. VII.

The most stable combination of this Gas with water, forming a liquid Acid that may be distilled over, has Specific Gravity = 1.4237, and contains probably four atoms of water to one of real Acid. It boils at 248° Fahrenheit. The density at which nitric Acid most readily freezes, is, according to Mr. Cavendish, that of Specific Gravity 1.3, requiring a temperature of − 2° Fahrenheit. Two parts of Acid rapidly mixed with one part of water, both at 58° Fahrenheit, produce an elevation of temperature equal to 120° Fahrenheit. And fifty-eight parts by weight of Acid, Specific Gravity 1.50, added to forty-two parts of water, both at 60° Fahrenheit, are raised to 200° Fahrenheit. (*w*.)

The force with which this Acid retains its oxygen is not very considerable, so that combustible bodies readily decompose it: hence its effects on most of the metals. Thus also hydrogen decomposes it when heated, and produces a violent explosion. Essential oils produce an analogous effect, but the experiment is one requiring great caution.

This Acid is of great service in the Arts as a solvent of metals; and it has been employed partially in Medicine, but it does not appear to possess any very specific action on the human frame.

Nitro-Muriatic Acid.

(459.) For the sake of simplicity we retain the old name for this Acid, which is not, in fact, to be considered as even a proximate element, but only a compound frequently employed in Chemical researches. It is generally formed by mixing two parts of nitric Acid with one of hydrochloric Acid by weight; or even by one part of the former to four of the latter; a variation which abundantly proves either that the proportions are not very important, or that the rationale of the effects produced is not understood. The latter point has indeed been partially examined by Sir H. Davy. (*x*.) He "has rendered it probable that the peculiar properties of this Acid are owing to a mutual decomposition of the nitric and muriatic Acids, the oxygen of the former uniting with the hydrogen of the latter, in consequence of which water, chlorine, and nitrous Acid are the results. For every 101 parts by weight of real nitric Acid (equivalent to 118 of hydronitric Acid) which are decomposed, 67 parts of chlorine, he calculates, are produced. According to this view, it is not correct to say that *aqua regia* (the old name of Nitro-Muriatic Acid) oxidates gold or platinum, since it merely causes their combination with chlorine. By long-continued and gentle heat Nitro-Muriatic Acid may be entirely deprived of chlorine, and it then loses its power of acting on gold or platinum.

"The Nitro-Muriatic Acid does not form with alkaline or other bases a distinct genus of Salts, entitled to the name of nitro-muriates; for when combined with an alkali, or an earth, the solution yields on evaporation a mixture of a muriate and a nitrate; and metallic bodies dissolved in it yield muriates only." Henry.

Subsect. 7.—Ammonia.

(460.) A. The liquid solution of Ammonia in water was known to the Alchemists, as it is mentioned in the writings of Basil Valentine and Raymond Lully. Dr. Black first pointed out the difference between its pure and its carbonated form, and Priestley first examined it as a Gas, calling it alkaline air. It is found in combination with Acids among volcanic products, and it is disengaged together with other Gases during the spontaneous decomposition of putrescent animal and vegetable matter.

(461.) B. Pure ammoniacal Gas is readily obtained for experiment by applying a lamp-heat to common *liquor Ammoniæ* in a gas bottle with a bent tube. The Gas must be collected over mercury; or it may be produced by mixing equal parts of dry Sal ammoniac (hydrochlorate of Ammonia) with dry quick-lime, both in fine powder, and applying a lamp-heat, collecting the Gas as before. This Gas, which of course is the most pure form of the volatile alkali, consists of nitrogen combined with hydrogen in the proportion of one volume or atom of the former + three volumes or atoms of the latter condensed into two volumes. The synthetic union of these elements has not yet been effected, but the decomposition of Ammonia fully proves the accuracy of such a view of its constitution. It was analysed by A. Berthollet, and most satisfactorily by Dr. Henry, (*z*.) by detonation with oxygen. For the method of obtaining Ammonia for Medical and Commercial purposes, we must refer to Mr. Richard Phillips's excellent translation of the *Pharmacopœia*. (*y*.)

(462.) C. Ammoniacal Gas has a most pungent odour. It extinguishes flame, and when undiluted, cannot be respired. It is not sufficiently inflammable to burn in atmospheric air; but Dr. Henry found that he could ignite a small jet of it issuing into an atmosphere of oxygen Gas. It is lighter than atmospheric air, as will be seen from the table of Specific Gravity in Part V. Heat is capable of decomposing it when passed through a porcelain tube; so also is a current of electric sparks. Water will absorb 190 per cent. by volumes of this Gas. Its properties are decidedly alkaline, as it turns vegetable blues to green, and saturates Acids so as to form a class of Salts. At 50° Fahrenheit, and under a pressure of 6.5 atmospheres, Ammonia becomes a limpid colourless Liquid.

(463.) D. Oxygen has no immediate action on am-

Hydrocyanic Acid.—Prussic Acid, Scheele.

(474.) Scheele discovered this Acid in 1782; and Berthollet ascertained its ultimate elements to be carbon, nitrogen, and hydrogen. Gay Lussac, by discovering the true nature of cyanogen, showed it to be the base of the Acid, and hydrogen the acidifying principle.

Hydrocyanic Acid is obtained by heating three parts of cyanuret of mercury with two parts by weight of concentrated hydrochloric Acid in a glass retort. A vapour of water, hydrochloric Acid, and Hydrocyanic Acid rises, and is purified from the hydrochloric Acid by being suffered to pass through a narrow tube, containing fragments of marble, which take up the latter Acid. It is next conveyed through dry chloride of calcium, and condensed in a vessel surrounded with ice.

Vauquelin, however, recommends in preference, that a narrow horizontal tube should be filled with fragments of the mercurial cyanuret; and that then a current of hydrosulphuric Acid Gas should be slowly admitted. The instant that Gas comes in contact with the cyanuret, double decomposition ensues; Hydrocyanic Acid and the black sulphuret of mercury being generated. The progress of the hydrosulphuric Acid along the tube may be distinctly traced by the change of colour, and the experiment may be terminated so soon as the whole of the cyanuret has become black. The Hydrocyanic Acid is then to be expelled by a gentle heat, and collected in a cool receiver.

For Medicinal purposes it is prepared at Apothecaries' Hall, by mixing in a retort one part of cyanuret of mercury, one part of hydrochloric Acid, (Specific Gravity 1.15,) and six parts of water. This is distilled at a gentle heat, giving an Acid of Specific Gravity 0.995. (*ff*)

Pure condensed Hydrocyanic Acid is a limpid Fluid of Specific Gravity 0.7058. at 45° Fahrenheit. It has a strong odour of the peach blossom, and the vapour, when breathed even with much atmospheric air, produces giddiness and headach. When diluted, it has the taste of bitter almonds. This Acid is extremely volatile, and boils at 79° Fahrenheit: at zero it congeals. Even when closely confined, it most readily undergoes spontaneous decomposition, so that it cannot well be preserved undiluted many days. During decomposition it assumes a brownish tint. It reddens litmus-paper feebly, and combines with bases to form Salts; but it is so feeble as not to decompose the carbonates, nor can it be made to neutralize potassa.

By Voltaic electricity it is decomposed, the hydrogen appearing at the negative pole, the cyanogen at the positive one. It is also partially decomposed by being passed through a red-hot porcelain tube. With oxygen Gas it detonates in Volta's eudiometer. It is best analysed by potassia, as in Gay Lussac's experiments.

Free Hydrocyanic Acid is readily recognised by its odour. A fluid which is supposed to contain it may be agitated with finely-powdered oxide of mercury. By double decomposition water and cyanuret of mercury are produced, and on evaporating the filtered solution, small crystals of the cyanuret are obtained.

Dr. Ure has given the following process for estimating the strength of any solution of Hydrocyanic Acid met with in commerce. "To 100 grains of the Liquid contained in a phial, let small given quantities of the finely-powdered peroxide of mercury successively be added, until it ceases to be dissolved. The weight of peroxide so dissolved, divided by four, gives the quantity of real Hydrocyanic Acid present." (*gg.*)

The distilled water of the ***Prunus Lauro-cerasus*** owes its odour and poisonous properties to this Acid; it exists also in the bitter almond, and in the bird-cherry.

The Hydrocyanic Acid, when pure, is so violent a poison, that one drop may be fatal. In a diluted state it is now given Medicinally with much success, chiefly to allay irritation in pulmonic complaints. (*hh.*)

Chlorocyanic Acid.

(475.) If chlorine Gas be passed through an aqueous solution of hydrocyanic Acid, until the Liquid acquires bleaching properties, and then the redundant chlorine be removed by agitation with mercury, two Acids remain, the hydrochloric, and the Chlorocarbonic, first called the Oxyprussic by Berthollet. This Acid is at present little known, and seems scarcely to have been obtained in a separate state. Its composition, as stated by M. Gay Lussac, has been already mentioned.

Iodide of Cyanogen; or Cyanuret of Iodine.

(476.) Such are the names given to a compound of these elements not possessed of acid properties. It was discovered in 1824 by M. Serullas, and may be obtained by mixing two parts of cyanuret of mercury with one of Iodine, both quite dry, in a glass mortar. This mixture is to be put into a wide-mouthed phial. On the first application of heat, vapours of Iodine appear, but so soon as the Cyanuret undergoes decomposition, white fumes are seen, which will condense on the sides of a cool glass receiver in flocculi like cotton wool.

This Iodide of Cyanogen has a caustic taste and acrid odour, exciting tears. It is very volatile, and bears a heat of more than 212° Fahrenheit, without decomposition, but its elements are disunited by a red-heat. It is soluble in water. (*ii.*)

Ferro-hydrocyanic Acid. Ferruretted Chyazic Acid. (Porrett.) Ferro-cyanic Acid. Acide Hydro-cyanique ferruré. (Thenard.)

(477.) We are disposed to prefer the name standing first among these synonymes, as best expressing the constitution of this Acid; *viz.* that iron and hydrogen both simultaneously combine in forming an acid compound, having cyanogen for a base. Or it might possibly be said that iron in combination exerts a modifying agency upon what would otherwise be Hydrocyanic Acid. Mr. Porrett, to whom, with Messrs. Wilson and Rupert Kirk, we are much indebted for able researches into the nature of these interesting compounds, proposed the name of Chyazic Acid, forming the word from the initial parts of its elements, carbon, hydrogen, and azote. We object to the name of Ferrocyanic Acid, because it would seem to express the nature of the substance, and yet omits an important element. By some it is considered that hydrogen acts as the acidifying principle upon a sort of double radical consisting of both cyanogen and cyanuret of iron.

The following are two processes recommended by Mr. Porrett for obtaining this Acid. 1. Let 58 grains of crystallized tartaric Acid be dissolved in alcohol, and

Order 1.—*Brittle and Acidifiable.*

Arsenic.
Tungsten.
Molybdenum.
Chromium.

Order 2.—*Brittle and simply Oxidable.*

Titanium.
Uranium.
Cobalt.
Manganese.
Bismuth.
Antimony.
Tellurium.

Order 3.—*Oxidable and imperfectly Ductile.*

Mercury.
Zinc.

Order 4.—*Easily Oxidable and Ductile.*

Tin.
Lead.
Iron.
Copper

Order 5.—*Difficult of Oxidation and very Ductile.*

Silver.
Gold.
Palladium.
Platinum

Another arrangement was proposed by Dr. Thomson in the 3d Edition of his *Chemistry*, and is employed by Dr. Henry. Here there are four Classes.

Class 1.—*Malleable Metals.*

Gold
Platinum.
Silver.
Mercury.
Palladium.
Rhodium.
Iridium.
Osmium.
Copper.
Iron.
Nickel.
Tin.
Lead.
Zinc

Class 2.—*Brittle and easily fused.*

Bismuth.
Antimony.
Tellurium.
Arsenic.

Class 3.—*Brittle and difficult of Fusion.*

Cobalt.
Manganese
Chromium.
Molybdenum.
Uranium.
Tungsten.

Class 4.—*Refractory Metals.*

Titanium.
Columbium.
Cerium.

In the most recent edition of Dr. Thomson's Work, arsenic, tellurium, and osmium are removed from the rank of Metals, and fall in with his " acidifiable combustibles," phosphorus, sulphur, &c. Then come 31 Metals, which form " *alkalis* or *bases* capable of constituting neutral Salts with Acids, by uniting with the supporters of combustion." These are arranged under five Families.

Family 1. contains those bodies which, " when combined with oxygen, possess the alkaline properties in the greatest perfection. They all convert vegetable blues to green, and are all soluble in water, with the exception of magnesia," which is so to only a very slight extent. Here we have the bases of the alkalis and alkaline earths of former Chemists

1. Potassium.
2. Sodium.
3. Lithium.
4. Calcium.
5. Borium
6. Strontium.
7. Magnesium.

Family 2.—The compounds which the elements contained in this Family " form with oxygen are white, and these oxides form colourless solutions in Acids; it has hitherto been impossible to reduce them in any quantity to the Metallic state. They are insoluble in water, and produce no alteration in the colour of vegetable blues. On that account they were formerly distinguished in Chemistry by the name of *earths proper*."

1. Yttrium.
2. Glucinum.
3. Aluminum.
4. Zirconium.
5. Thorinum.

Family 3.—The Metals in this Family " are distinguished by two properties: 1. Their oxides cannot be reduced to the Metallic state by the most violent heat that can be applied. 2. When dissolved in an Acid they cannot be precipitated in the Metallic state by plunging into the solution a rod of any other Metal."

1. Iron.
2. Nickel.
3. Cobalt.
4. Manganese.
5. Cerium.
6. Uranium.

Family 4.—The substances belonging to this Family " are precipitated from their solutions in Acids, in the Metallic state, in the order of the following Table. Zinc precipitating all the others; but not being itself precipitated by any of them. Lead precipitates all except zinc and cadmium. Tin all except zinc and lead. Copper precipitates only bismuth, mercury, and silver. Silver is precipitated by all the rest, but does not itself precipitate any of the others."

1. Zinc.
2. Cadmium.
3. Lead.
4. Tin.
5. Copper.
6. Bismuth.
7. Mercury.
8. Silver.

Family 5.—In this Family, consisting of five Metals, " they all require a strong heat to fuse them; they are all insoluble in nitric Acid, and their oxides are reducible to the Metallic state by the application of heat alone."

1. Gold.
2. Platinum.
3. Palladium.
4. Rhodium.
5. Iridium.

The remaining Metals which in Dr. Thomson's system do not enter any of these Families constitute a genus apart. They are described as " bodies producing by their union with the supporters of combustion imperfect Acids, or substances intermediate between Acids and alkalis."

1. Antimony.
2. Chromium.
3. Molybdenum.
4. Tungsten.
5. Columbium.
6. Titanium.

(481.) We now proceed to that classification of the Metals which we have adopted in this Essay. It is almost identical with that made use of by M. Thenard in former editions of his admirable *Traité de Chimie;* but it differs in that we have already treated of silicon by removing it from the class of Metals: a measure justified by the opinions of Thomson and Berzelius. In the last edition of M. Thenard's Work (the fifth) he has placed *silicon* and *zirconium* in a division by themselves as intermediate between the substances of our third Chapter and the Metals. Berzelius has recently ascertained that *thorina*, which he had considered a peculiar earth, is a phosphate of yttria. The name, however, still remains in our Synopsis, as the same

Chemist has discovered another earth which he deems a simple substance, and from a similarity of properties proposes that it should occupy the vacant name. The following forty Metals then will stand in six classes, chiefly dependent for their distinction upon the degree of their affinity for oxygen.

(482.) *Class* 1.—Those Metals which have not yet been actually obtained by reduction from their oxides, and exhibited in a pure state, though considered Metals on sufficiently strong analogies.

1. Zirconium.
2. Thorinum?
3. Aluminum.
4. Yttrium.
5. Glycynum.
6. Magnesium.

(483.) *Class* 2.—Metals which instantly decompose water at ordinary temperatures; combine with oxygen Gas at the same temperature, or by the aid of a slight heat; and whose oxides are reducible by Electricity, or by certain very combustible bodies; but cannot be reduced by heat alone.

1. Potassium.
2. Sodium.
3. Lithium.
4. Barium.
5. Strontium.
6. Calcium.

(484.) *Class* 3.—Metals which are capable of decomposing water but only at a red heat; which combine with oxygen at some temperature; and whose oxides are reducible by electricity, and by different combustible bodies, though not reducible by any heat alone however violent.

1. Manganese.
2. Zinc.
3. Iron.
4. Tin.
5. Cadmium.

(485.) *Class* 4.—The Metals of this section are incapable of decomposing water at any temperature; they combine with oxygen upon some elevation of temperature; their oxides are reducible by Electricity, and by different combustible bodies, but not reducible by heat alone.

The Metals of this section are again subdivided into first, those which are capable of becoming Acids; and secondly, those which form oxides only.

Acidifiable.

1. Arsenic.
2. Molybdenum.
3. Chromium.
4. Tungsten.
5. Columbium.

Not Acidifiable.

1. Antimony.
2. Uranium.
3. Cerium.
4. Cobalt.
5. Titanium.
6. Bismuth.
7. Copper.
8. Tellurium.
9. Nickel.
10. Lead.

M. Thenard suggests that some of these, especially antimony, titanium, and tellurium, have a claim to be considered acidifiable Metals.

(486.) *Class* 5.—Metals which do not decompose water at any temperature, but which combine with oxygen at some temperature or other, and whose oxides are reducible by heat alone.

1. Mercury.
2. Osmium.

(487.) *Class* 6.—Those Metals which do not decompose water at any temperature: do not combine with oxygen at any temperature; and whose oxides formed indirectly are easily reducible by heat alone.

1. Silver.
2. Palladium.
3. Rhodium.
4. Platinum.
5. Gold.
6. Iridium.

METALS. CLASS I.

Sect. I.—*Zirconium.*

(488.) Of this Metal, the oxide of which forms the earth Zirconia, (see subsect. 1.) we have few details, and for the slender knowledge which we possess, we are entirely indebted to Sir H. Davy. He submitted the earth Zirconia, in contact with potassium and mercury, to the action of Voltaic Electricity, and obtained results which showed that some portion of the earth had undergone decomposition; the metallic amalgam being capable of decomposing water, and the Zircon earth being found as a product after that decomposition. Davy also applied potassium to Zirconia at a white heat: the potassium "was for the most part converted into potash, and dark particles, which, when examined with a magnifying glass, appeared metallic in some parts, and chocolate brown in others, were found diffused through the potash and the undecomposed earth." (*a.*)

Subsect. 1.—*Zirconia.*

(489.) A. By analyzing Zircon, a mineral found in the Island of Ceylon, Klaproth, in the year 1789, discovered a new earth, which he named Zirconia. (*b.*) In 1795 he published his Analysis of the Hyacinth, another mineral from the same island, and found in this also a considerable proportion of the same earth. (*c.*) Morveau then, in 1796, examined the Hyacinths from Expailly in France, in which he also found Zirconia. (*d.*) Vauquelin has also given some Memoirs on this subject; (*e.*) and still more recently, M. Chevreul. (*f.*) MM. Dubois and Silviera have proposed an improved process for obtaining this earth. (*g.*)

(490.) B. This process consists in submitting the Zircons, reduced to a fine powder, and mixed with two parts of pure potash, to a red heat for an hour in a silver crucible. The mass is then treated with distilled water filtered and thoroughly washed. The residuum upon the filter consists of Zirconia, silica, with some potash, and oxide of iron. It is then dissolved in hydrochloric Acid, and evaporated to dryness, for the purpose of separating the silica. Let the muriate of Zirconia and iron be redissolved in water; and to separate a little Zirconia which will adhere to the silica, wash the latter with a little weak hydrochloric Acid, and add this to the solution. After filtering the Liquid, let the Zirconia and iron be precipitated by pure ammonia; wash the precipitate well, and treat it with oxalic Acid, boiling them well together; by this the oxide of iron will be dissolved out, and an insoluble oxalate of Zirconia will be formed. Filter and wash the oxalate until no iron can be detected in the washing. The oxalate of Zirconia well washed and dried is of an opaline colour, and may be decomposed by heat in a platinum crucible.

(491.) C. Zirconia is a fine, white powder without taste or smell, but feeling gritty between the fingers; infusible save by the Gas blowpipe. It is insoluble in water, but has a strong affinity for that Liquid. When slowly dried, after being precipitated from a solution, it retains about one-third its weight of water, and assumes a yellow colour, with some degree of transparency, which gives it the appearance of gum arabic.

(492.) D. E. F. G. none, or unnoticed.

(493.) H. Zirconia does not combine with these nonmetallic substances.

(494.) I. Neither has it any other known action with the Metals, save that which has been already noticed in sect. 1.

(495.) Zirconia is insoluble in liquid caustic alkalis, neither does it combine with them by means of heat; but it is soluble in the liquid alkaline carbonates. It unites with silica and alumina by fusion, as also with some of the metallic oxides.

After precipitated Zirconia has been exposed to a red heat, or even well dried, it scarcely can be said to be soluble in Acids, but when newly precipitated, and still moist, it dissolves readily.

The greater part of the Salts of Zirconia are insoluble in water; "such are the sulphate, sulphite, phosphate, fluate, borate, carbonate, seleniate, oxalate, tartrate, citrate, saclactate, and gallate. But the hydrochlorate, nitrate, acetate, benzoate, and mallate are soluble." (Thomson.) The Salts of Zirconia have a harsh, astringent, disagreeable taste, similar to that of some of the metallic Salts. (*e*.)

(496.) L. Sulphuric Acid added to a neutral solution of Zirconia, if not too dilute, produces a white precipitate. Carbonate of ammonia produces also a white precipitate, soluble in excess of the reagent, by which Zirconia is distinguished from alumina. Oxalate of ammonia and tartrate of potash also produce white precipitates of the insoluble oxalate and tartrate. Hydrosulphuret of potash produces no precipitate, but infusion of galls will give a white one.

(497.) M. None.

References to § 1.

(*a*.) Davy, *Elements*, p. 360. (*b*.) *Jour. de Phys.* vol. xxxvi. p. 180. (*c*.) Klaproth, *Beitrage*, vol. i. p. 231. (*d*.) *An. de Ch.* vol. xxi. p. 72. (*e*.) Vauquelin, *An. de Ch.* vol. xxii. p. 158, and *Jour. des Mines*, No. 5. p. 97. (*f*.) Chevreul, *An. de Ch. et Ph.* vol. xiii. p. 245. (*g*.) *An. de Ch. et Ph.* vol. xiv. p. 110.

Sect. II.—*Yttrium.*

(498.) The name Yttrium has been assigned to the supposed base of the earth yttria. Of the existence of this Metal experiments similar to those made upon zirconia seemed to afford to Sir H. Davy sufficient proof. According to this opinion, which is generally received, yttria is a metallic oxide. Its properties will fall under the following subsection.

Subsect. I.—*Yttria.*

(499.) A. "Some time before 1788, Captain Arhenius discovered, in the quarry of Ytterby, in Sweden, a peculiar mineral." This mineral is now called Gadolinite, after its first analyst. It was first described by Gayer in Crell's *Annals* for 1788. Professor Gadolin analyzed this mineral in 1794, (*a*.) and found it to contain a new earth; but though his analysis was published in the *Stockholm Transactions* for 1794, and in Crell's *Annals* for 1796, it was some time before it attracted the attention of Chemical mineralogists. The conclusions of Gadolin were confirmed by Ekeberg in 1797, who gave to the new earth the name of Yttria. (*b*.) These researches were still further extended by Vauquelin in 1800; (*c*.) and likewise by Klaproth about the same time: (*d*.) Ekeberg also published a new dissertation on the subject in the *Swedish Transactions* for 1802. (*e*.) Since that time Yttria has been repeatedly examined by Berzelius, who has shown (*f*.) that the earth examined by Ekeberg and Gadolin was not pure. He has himself succeeded in separating it from most of the cerium with which it was contaminated, and has described its properties. (*g*.)

Yttria has as yet only been found in the Gadolinite above mentioned; in yttro-tantalite another Swedish mineral, where it is combined with tantalum; and in combination with phosphoric Acid, by which it produced the earth to which Berzelius had given the name of Thorina, supposing it to be a new proximate element.

(500.) B. Yttria is obtained from yttro-tantalite, the more plentiful mineral, by the following process. The pulverized mineral is to be dissolved in nitro-muriatic Acid. The solution is then to be highly concentrated by evaporation, then filtered and diluted with water. Thus the silica is in a great measure got rid of. The filtered Liquid is to be evaporated to dryness, and the residue submitted for some time to a red heat in a close vessel, and then redissolved in water and filtered. To the clear solution let ammonia be added, and a mixture of Yttria and oxide of cerium is precipitated. Heat this powder to redness, dissolve in nitric Acid, and again evaporate to dryness, to get rid of the excess of Acid. Add 150 parts of water, and put into the Liquid crystals of sulphate of potash. The crystals gradually dissolve, and after some hours a white precipitate of oxide of cerium appears. The latter process is to be repeated to be certain of having got rid of all the oxide of cerium. The Yttria may be precipitated from the filtered liquor by pure ammonia, and after being well washed is to be heated to redness. (*f*.)

(501.) C. Yttria produces neither taste nor smell, nor has it any effect on vegetable colours. It is heavier than the other earths, its Specific Gravity being 4.84, according to Ekeberg. It is insoluble in water, but absorbs and strongly retains that fluid.

(502.) D. E. F. G. It is not probable that Yttria has any mutual action with these substances.

(503.) H. Neither is it likely that it would unite with any substance in this division, as Klaproth could not produce a combination with sulphur.

(504.) K. Yttria is not soluble in the liquid caustic alkalis, nor is it redissolved by excess after having been precipitated by them from its solutions. In this it differs from glycyna. Like glycyna, it is soluble in carbonate of ammonia, but requires five or six times the quantity of that menstruum.

Yttria combines with the Acids, exerting considerable strength of affinity, as it precipitates alumina, zirconia, and glycyna from their solutions. It is itself precipitated by the alkalis and alkaline earth. Its Salts, when quite pure, are colourless, and have a sweet taste. Those which are soluble, the sulphate, nitrate, hydrochlorate, and acetate, are crystallizable: they are always acidulous, the chromate excepted; but even with this excess of Acid, they refuse to dissolve any additional portion of the earth. The insoluble Salts, *viz.* the phosphate, arseniate, carbonate, seleniate, oxalate, tartrate, succinate, and citrate, are, however, neutral.

(505.) L. Yttria is precipitated by prussiate of potash of a greyish colour. Also in grey flocculi by infusion or tincture of galls, but very slightly by pure gallic Acid. Its saline solutions are not affected by hydrosulphuric Acid, nor by sulphuret of ammonia. It is also precipitated by phosphate of soda, carbonate of soda, and oxalate of ammonia.

(506.) M. None.

References to § 2.

(*a.*) Gadolin, Crell's *Annals*, 1796, p. 313. (*b.*) Crell's *Annals*, 1799, vol. ii. p. 63. (*c.*) Vauquelin, *An. de Ch.* vol. xxxvi. p. 143. (*d.*) Klaproth, *Beit.* vol. iii. p. 52; *An. de Ch.* vol. xxxvii. p. 86. (*e.*) Ekeberg, *Kongl. Vetenskaps Acad. nya Handlingar*, 1802, p. 86; or *Jour. de Ch.* vol. iii. p. 98. (*f.*) *Afhandlingar, &c.*, vol. iv. p. 217—235; or *An. Phil.* vol. iii. p. 359; or *An. de Ch. et Ph.* vol. iii. p. 26—33. (*g.*) Thomson, *Chem.* vol. i. p. 369.

Sect. III.—*Glycynum.*

(507.) For the existence of this Metal we have the same evidence as is exhibited in the case of zirconium, and for this knowledge we are also indebted to Sir H. Davy. The process he employed was the same as he made use of for zirconium. (488.) The oxide of Glycynum forms the earth glycyna, which we shall describe in the following subsection.

Subsect. 1.—*Glycyna.*

(508.) A. In the year 1798, the Abbé Haüy requested Vauquelin to analyze the emerald and beryl, in consequence of an inference which he had deduced from their crystalline forms, that the two minerals contained the same chemical elements. Haüy's conjecture was confirmed by the analysis, and Vauquelin was rewarded by the discovery of a new earth, to which the name of Glycynum was given, in consequence of the sweet taste of its Salts. (γλυκὺς.) Vauquelin's experiments (*a.*) have been repeated by Klaproth, (*b.*) and Ekeberg, (*c.*) and Berzelius. Glycyna is found in the emerald, beryl, and euclase. It has been usual to write this word Glucina, but the ordinary laws of derivation from its Greek source require that it should be Glycina, or even in still greater strictness Glycyna.

(509.) B. To obtain this earth, the mineral containing it is to be finely powdered, and then fused with thrice its weight of potash. To the fused mass add a little water, and then dissolve in hydrochloric Acid; evaporate the solution to dryness. Add then abundance of water, and filter out the silica. The muriates of Glycyna, &c. pass through in solution. Precipitate the earths by carbonate of potash. Wash the precipitate well, and dissolve it in sulphuric Acid. Then to this solution add a solution of sulphate of potash; concentrate by evaporation, and leave the Liquid to crystallize. Crystals of alum are thus removed. When as many of these have been obtained as is possible, add carbonate of ammonia in excess, filter and boil the Liquid for some time. The Glycyna gradually subsides in the form of a white powder.

(510.) C. Glycyna is a soft, white powder, infusible save by the Gas blowpipe, causing neither taste nor smell, but adhering to the tongue. It does not affect vegetable colours, is insoluble in water, but forms a paste with that Liquid.

(511.) D. E. F. G. These have no action on Glycyna.

(512.) H. With the simple combustibles it does not combine.

(513.) I. Nor yet with the metals.

(514.) K. Glycyna is soluble in solutions of the fixed alkalis like alumina. It agrees with yttria in being insoluble in ammonia, but soluble in its carbonates, though in a much greater degree. It is soluble also in the other alkaline carbonates. Glycyna readily combines with all the Acids, and even the hydrosulphuric. Its Salts are for the most part soluble in water, but the greater part are not crystallizable. The carbonate, phosphate, seleniate, and succinate are insoluble.

(515.) L. Prussiate of potassa gives a white, and infusion of galls a yellow, precipitate when added to the solution of a salt of Glycyna. In its solubility in potassa and soda; Glycyna resembles alumina; but Vauquelin showed that it would not form alum by adding potassa to its liquid sulphate: and further by the sweet taste of its Salts he considered it clearly distinguished from that earth. It differs also from Yttria in not forming crystallizable Salts, in not being soluble in the fixed alkalis, and in not being precipitated by oxalate of ammonia, nor by tartrate or citrate of potash.

References to § 3.

(*a.*) Vauquelin, *An. de Ch.* vol. xxvi. p. 155, and *An. d'Hist. Nat.* vol. xv. p. 358—395. (*b.*) Klaproth, *Beitrage*, vol. iii. p. 215. (*c.*) Ekeberg, *An. de Ch.* vol. xliii. p. 277, or *Jour. des Mines*, vol. xii. p. 25.

Sect. IV.—*Thorinum.*

(516.) At the time of forming the outline of this Treatise, it was believed, on the authority of Berzelius, that a peculiar earth existed, to which he gave the name of Thorina; and from analogy with other earths it was supposed to have a metallic base, which would of course be Thorinum. Berzelius has, however, subsequently found that this supposed earth, of which he had only a very small quantity, was a phosphate of yttria. Still more recently he has obtained another earth, which he believes to be simple, and proposes that it should still continue the name of Thorina among the earths. At present, however, very little is generally known of this substance.

Sect. V.—*Aluminum.*

(517.) The experiments of Sir H. Davy on the earth alumina gave sufficient evidence of the existence of this Metal, though they were not so successful as those made on some of the other earths. He submitted alumina fused with potash to the action of Voltaic Electricity, and obtained metallic globules, consisting chiefly of potassium, but which, when carefully separated and again oxidized, afforded both potash and alumina. Results of the same nature were obtained from potassium and from mercury, when acted upon in a state of mixture with alumina. By exposing the earth at a white heat to the vapour of potassium, potash was formed, and among the alumina there appeared small particles of a grey colour and metallic lustre, which again became white on exposure to the air, or if placed in water decomposed, it producing a slight effervescence. Alumina, a well-known earth, the oxide of this Metal, will be described in the following subsection.

Subsect. 1.—*Alumina.*

(518.) A. "Alum is a salt which was known many centuries ago, and employed in dyeing, though its component parts were unknown. The alchemists discovered that it is composed of sulphuric Acid with an earth; but the nature of this earth was long unknown. Stahl and Neuman supposed it to be lime; but in 1728, Geoffroy, jun. proved this to be a mistake, and demonstrated that the earth of alum constitutes a part of clay. (*a.*) In 1754, Margraaf showed that the basis of alum is an earth of a peculiar nature, different from every other; an earth which is an essential ingredient in clays, and gives to them their peculiar properties. (*b.*) Hence this earth was called *Argil;* but Morveau afterwards gave it the name of *Alumina,* because it is obtained in the state of greatest purity from alum. The properties of Alumina were still further examined by Macquer in 1758 and 1762, (*c.*) by Bergman in 1767 and 1771, (*d.*) and by Scheele in 1776; (*e.*) not to mention several other Chemists who have contributed to the complete investigation of this substance. A very ingenious Treatise on it was published by Saussure, jun. in 1801." (*f.*) Thomson, *Syst.* vol. i. p. 373.

Alumina forms a part of many minerals. It exists pure in the corundum genus, of which the sapphire and ruby are species; owing their colours only to very minute portions of metallic oxides. Alumina forms the characteristic ingredient in clays and marls, and it is to this earth that they are indebted for their plastic properties.

(519.) B. To obtain pure Alumina, let alum be dissolved in about twenty times its weight of water, then add a small quantity of carbonate of soda in solution to precipitate a little iron, with which almost all alum is contaminated. After this let the Liquid be filtered into a solution of pure ammonia, being careful to keep the latter alkali in excess. The ammonia unites with the sulphuric Acid, and the Alumina falls down in a white flocculent precipitate, which must be well washed and dried. According to Saussure there is a considerable difference in the appearance of precipitated Alumina, arising from the state of dilution in which it exists in its solution.

(520.) C. Pure Alumina is a white, bland powder, adhering to the tongue, but neither exciting smell nor taste. It forms a paste with water: is infusible, except by the flame of the Gas blow-pipe. There is a peculiar smell excited by breathing upon an argillaceous limestone, but this smell depends upon the simultaneous presence of oxide of iron. The Specific Gravity of Alumina is 2.0, according to Kirwan. When first precipitated, Alumina is a hydrate, but by a red heat the water is driven off, and the chemical properties of the earth itself undergo some change. On this subject consult Saussure's Memoir, and some interesting recent experiments by Thomson. (*g.*)

(521.) D E. F. G. H. I. With the substances in these classes Alumina does not combine.

(522.) K. In considering the action of Alumina with the bases, we may first notice its ready power of union with other earths by fusion. From this property arises much of its utility in the Arts. Thus it unites with lime, barytes, strontia, magnesia, and silica, and probably would do so with the other similar bodies. With those named it combines both in the humid and dry way. The affinity for barytes is very marked, for it communicates to Alumina a degree of solubility beyond that which is natural to it, so that when equal parts of these earths are boiled in water, both are dissolved. Vauquelin states that if barytic water be added to a solution of muriate of Alumina a precipitate falls consisting partly of both earths. (*h.*) This, however, is denied by Chenevix and Darracq. The effect of strontia is analogous, for if five parts of this earth be boiled with one of Alumina, a portion of Alumina is rendered soluble, while another portion remains in the state of an insoluble compound of strontia and Alumina. Scheele observed, that when Alumina is added to lime-water, an insoluble compound of the two earths is precipitated. Chenevix found that if a solution of potash be boiled on a mixture of lime and Alumina, the latter is dissolved; together with a greater proportion of lime than is due to the solvent power of the water alone: while if the alkaline solution be boiled on lime alone, no more lime is dissolved than is due to the water of the solution; a proof that the solvent power of the water over the lime is promoted by the Alumina.

By the intense heat of the Gas blow-pipe, or of oxygen alone, Alumina and lime may be fused together when the Alumina is in excess: but Alumina and magnesia will not run together at any heat, according to Kirwan and Guyton. There is, however, some affinity between Alumina and magnesia, for magnesia alone cannot be entirely precipitated from any of its solutions by ammonia, while if Alumina be present its precipitation is complete. Thus Chenevix found, that if an excess of Ammonia be added to a solution of muriate of magnesia, mixed with a large proportion of muriate of Alumina, nothing remained in solution but muriate of ammonia; the two earths being precipitated in combination, and their mutual affinity was even sufficient to resist the action which potash exerts on aluminous earth.

The mutual attraction between silica and Alumina is shown by an experiment of Morveau, in which, when a solution of silicate of potash and of Alumina and potash are mixed, the two earths are precipitated in combination, by which the properties of each are modified. So also at a very intense heat this affinity is developed by the earths entering into fusion and forming a milky glass or enamel.

Alumina unites also with some of the metallic oxides by fusion, forming enamel of different colours.

Acids dissolve Alumina with ease, especially when it has been recently precipitated. The Salts thus formed are, for the most part, soluble in water, and, generally speaking, their tendency to crystallization is small. The arseniate, seleniate, tungstate, mallate, urate, saclactate, are insoluble; but for the properties of these Salts we must refer to the more extended chemical systems.

There is, however, one salt of Alumina of too great commercial importance to be passed by without further notice. Alum is a triple compound of Alumina, sulphuric Acid, and any one of the three alkalis proper, with some water of crystallization. Of this salt there are four varieties. We could have wished here to describe more fully the natural and chemical history of a substance so extensively employed in numerous Arts, but our space not permitting, we refer the reader to an excellent synoptic view of the subject given in Professor Thomson's *System*, vol. ii. p. 537.

(523.) L. One of the marked properties of the aluminous Salts is that they have in general a sweet taste, like those of glycyna. They are not precipitated from their solutions by oxalate of ammonia, nor by tartaric Acid, which distinguishes them from those of yttria. They are not precipitated by prussiate of potash, nor by tincture of galls, in which respect they differ from the salts of glycyna and yttria. If sulphuric Acid and then sulphate of potash be added to a salt of Alumina, and the mixture be left at rest, crystals of alum speedily form therein. Phosphate of ammonia produces a white precipitate; and hydriodate of potash a white flocculent precipitate, which speedily becomes of a permanent yellow colour.

(524.) M. The uses of Alumina and its compounds in the Arts and Manufactures are both numerous and important. Every variety of porcelain consists of some combination of argillaceous and silicious earths; though in the coarser kinds of pottery, sand and other impurities enter in considerable proportions. Silica, it is true, generally predominates even in the best porcelain clays, yet it is upon the Alumina that the essential properties of the compound depend. It is to this latter earth that the clay owes ductility in working, and tenacity in baking.

Generally speaking, the native porcelain clays increase in value in proportion to their purity. If more than five or six per cent. of lime be present, the clay becomes too fusible; if too great a proportion of oxide of iron be present, the porcelain acquires a red or brown tint when it is baked.

Of the porcelain clays the kaolin and petunze of the Chinese are the most celebrated. According to the analysis of Vauquelin, the former consists of silica 74, Alumina 14.5, lime 5.5. The purest clays that have been discovered in Europe result from the natural decomposition of rocks, containing a large proportion of feldspar. Such is the Cornish clay which is sent to Swansea, Worcester, and Coalbrook Dale. Magnesia seems also to be applicable to the same purpose, for Giobert found that a clay which had long been used with success in the manufacture of porcelain, consisted almost entirely of silica and carbonate of magnesia.

The colours on porcelain result from the fusion of certain metallic oxides; thus the purple precipitate of cassius, a preparation of gold, produces the carmine colour; and with a larger proportion of lead in the flux, the same substance gives a purple. Peroxide of iron produces rose-red; white oxide of antimony mixed with oxide of lead and silica gives a yellow; oxide of cobalt, blue; oxide of copper, green; and various shades of brown arise from using different proportions of the oxides of manganese, copper, and iron. The gilding upon china is performed by laying on the gold ground down to an extremely minute state of division in a varnish of borax and gum-water, which is fixed in burning by the fluxing properties of the borax, and afterwards polished with the burnisher.

Crucibles and retorts are formed from a clay containing much oxide of iron; and the Hessian crucible clay consists, according to Vauquelin, of silica 69, Alumina 21.5, charcoal 1, oxide of iron 8.0. The singular properties of alum are taken advantage of for the following purposes. To render wood fire-proof, which it effects to a very considerable extent. It will aid the separation of the serous and watery parts of cream in churning butter. The chandlers add it to tallow, for the purpose of giving hardness. It is used in silvering and lackering on copper and brass. It possesses a singular property in clearing turbid water, by producing a precipitate which settles to the bottom. It is used in tanning and dyeing the finer kinds of morocco leather. In dyeing cotton goods also it is of essential importance, as it both prepares the vegetable fibre for receiving the colours, and aids the formation of an actual chemical combination between its own base, the colouring matter, and the cotton that is to be dyed. In Medicine it is applied both internally and externally as an astringent. It adds to the tenacity of bookbinders' paste, and helps to preserve it.

The last of the uses of alum to which we shall advert, is in the formation of that singular substance Homberg's Pyrophorus.

(525.) "Let three parts of alum and one of flour or sugar be melted together in an iron ladle, and the mixture be dried till it becomes blackish and ceases to swell; if it be then pounded small, put into a glass phial, and placed in a sand-bath, heated till a blue flame issues from the mouth of the phial, and, after burning for a minute or two, be allowed to cool, this substance is obtained. It has the property of catching fire whenever it is exposed to the open air, especially if the air be moist." Such is Dr. Thomson's recipe, and we have frequently followed it, generally with success. Instead of a glass phial we place the mixture in a half-pint cucurbit, with a bit of glass tube luted into the mouth after the cucurbit is filled. The whole is submitted to a low red heat in a crucible of sand, placed within a small portable furnace. A blue flame issues from the orifice of the glass tube which may be suffered to burn for a quarter of an hour. The whole should then be withdrawn from the fire, and the tube closed with a piece of lute. When the whole is cool, the pyrophorus, a black pulverulent substance with some lumps, should be rapidly transferred to a dry stoppered bottle, and most carefully preserved from the air. In this manner we have kept it good for years, opening it only occasionally. If the pyrophorus does not ignite speedily when taken from the phial, the mere process of breathing on it will frequently cause a vivid ignition.

Homberg discovered this substance accidentally about the commencement of the XVIIIth century. Its singular properties have excited the attention of many Chemists; and Davy has made it appear that the igniferous property, for inflammable we ought not to say, depends upon a small quantity of potassium which is produced from the decomposition of the potash in making the pyrophorus.

References to § 5.

(*a.*) *Mém. Acad. Par.* 1728, p. 303. (*b.*) *Mém. Acad. Berlin*, 1754 and 1759. (*c.*) *Mém. Acad. Par.* 1728. (*d.*) Bergman, *Opusc.* vol. i. p. 287, and vol. v. p. 71. (*e.*) Scheele, *Essays*, vol. i. p. 191. (*f.*) *Jour. de Phys.* vol. lii. p. 289. (*g.*) *First Principles*, vol. i. p. 315. (*h.*) Vauquelin, *An. d'Hist. Nat.* vol. xv. p. 13. (*i.*) Chenevix, *Phil. Trans.* 1802, p. 346.

Sect. VI.—*Magnesium.*

(526.) For the discovery of this base we are indebted to that elaborate series of researches made by Sir H. Davy on the earths and alkalis in general.

When Magnesia, the oxide of this Metal, was submitted to galvanic action in its pure state, less effect was produced than upon the other alkaline earths. This was attributed to its very imperfect conducting power, arising out of its insolubility. To avoid this difficulty, solutions of the sulphate, or nitrate of Magnesia, were galvanized in contact with mercury. Decomposition then took place; an amalgam of mercury and Magnesium was formed. Sir H. Davy experienced, however, some difficulty in attempting to separate the Magnesium from the mercury, by distilling off the latter in a tube filled with the vapour of naphtha. The glass of the tube was acted upon, so that he was obliged at a certain period of the experiment to desist. Davy, however, obtained a Solid, having the same general metallic appearance as the Metals from the other earths had. "It sunk rapidly in water, though surrounded by globules of Gas, producing Magnesia, and quickly changed in air, becoming covered with a white crust, and falling into a fine powder, which proved to be Magnesia." (*a.*)

In a subsequent experiment, potassium was passed over Magnesia at a high temperature, and quicksilver introduced into the tube while hot. Thus an amalgam was obtained, from which the potassium was abstracted by the action of water. Thus a solid white metallic mass was obtained, which, by exposure to the air, became covered with a dry white powder; and by the action of hydrochloric acid, hydrogen was evolved in considerable quantity, and a solution of Magnesia obtained.

With Magnesium, oxygen combines to form the earth under examination, in the following subsection; and it is supposed to combine also with chlorine, as will there be noticed. It seems to be beyond a doubt, that if obtained in sufficient quantity, it would be found to possess all the ordinary characteristic properties of the metallic bodies.

Subsect. 1.—*Magnesia.*

(527.) A. "About the beginning of the XVIIIth century, a Roman Canon exposed a white powder for sale at Rome, as a cure for all diseases. This powder he called *Magnesia Alba.* He kept the manner of preparing it a profound secret; but, in 1707, Valentine informed the public that it might be obtained by calcining the lixivium which remains after the preparation of nitre: (*b.*) and, two years afterwards, Slevogt discovered that it might be precipitated by potash from the mother ley of nitre. This powder was very generally supposed to be lime, till F. Hoffman observed that it formed very different combinations with other bodies. (*c.*) But little was known concerning its nature, and it was even confounded with lime by most Chemists, till Dr. Black made his celebrated experiments upon it in 1755. Margraaf published a dissertation upon it in 1759: (*d.*) and Bergman another in 1775, in which he collected the observations of these two Philosophers; and enriched them by adding many observations of his own. (*e.*) Butine of Geneva likewise published a valuable dissertation on it in 1779." (Thomson.)

Magnesia exists naturally as a constituent part of several minerals and rocks. It seems to communicate to all the steatite family their peculiar soapy feel. It forms a part of the saline ingredients of sea-water, and its sulphate forms the chief active principle of many of the natural saline springs, so much the resort of invalids.

(528.) B. Pure Magnesia may be obtained by dissolving sulphate of Magnesia in hot water, and then adding to the filtered solution, while yet hot, a solution of carbonate of potash or soda, as long as any precipitate appears. The process is aided by gently boiling the Liquid. Thus we obtain a pure carbonate of Magnesia, which may be decomposed by a red heat, leaving pure Magnesia: hence sometimes called *Calcined Magnesia.*

(529.) C. Magnesia is a white, light powder, soft to the touch, without smell, and possessing only a rather bitter taste. It slightly changes the vegetable blues to green. It is, perhaps, the most infusible of the earths. Dr. Clarke succeeded in melting it by the flame of the Gas blowpipe, though with difficulty. Pure Magnesia is only soluble in 1600 times its weight of water, according to Dalton. When precipitated it retains some portion of water by a feeble affinity, thus constituting a hydrate. There is also a native hydrate containing thirty per cent. of water.

(530.) D. None.

(531.) E. If Magnesia be heated in chlorine Gas, a decomposition takes place, oxygen is evolved, and chloride of Magnesium is formed. The chlorine absorbed is double the volume of the oxgyen Gas evolved. When water is added to this compound, we have a well-known salt, which forms a part of the sea and many mineral waters. This salt, long called muriate of Magnesia, is, in fact, a hydrate of the chloride of Magnesium. It is a very deliquescent salt, soluble in twice its weight of alcohol, (0.817,) and in half its weight of water. When strongly heated, the water is dissipated, and in part decomposed. The hydrogen and chlorine escape, while the oxygen remains with the Metal to form Magnesia.

(532.) F. Unknown.

(533.) G. M. Gay Lussac formed the iodide of Magnesium, but its properties are little known.

(534.) H. With the exception of sulphur, it does not appear that any action takes place between the non-metallic electro-positive elements and Magnesia. Sulphur combines, but not very intimately, with Magnesia, when the former is fused in contact with it; or when the two are boiled together in water. Hydrosulphuric Acid Gas when passed through, which has Magnesia suspended in it, dissolves a small portion of the earth; but the properties of this compound are little understood.

(535.) I. With this class of bodies Magnesia has no action, save that which has been already mentioned under Magnesium. (526.)

(536.) K. With those metallic oxides that perform the part of bases, Magnesia has no action. With the Acids Magnesia readily combines as a base. Its Salts are in general of high solubility in water, and have for the most part a disagreeable, saline-bitter taste. They are crystallizable, but our space will not permit a detailed description of them. The carbonate and sulphate are, however, too important to be altogether passed over in silence.

(537.) The *Carbonate of Magnesia*, for medical use, is prepared as directed in Art. (528.) In this state it is a white powder, but having excess of base, so that it is not neutral. If, however, this powder be diffused through water, and a current of carbonic Acid Gas be passed through the Liquid, saturation is effected, and the powder is dissolved. The neutral salt thus formed, may be obtained by evaporation in the form of transparent hexagonal prisms with plane summits. The carbonate of Magnesia of commerce, consists of the first variety, and is according to Thomson generally contaminated with some sulphate of lime.

(538.) Sulphate of Magnesia was originally procured by evaporating the mineral spring which rises at Epsom in Surrey: hence it acquired the name of *Epsom Salt.* " Some account of it was published by Grew, in 1675; and, in 1723, Mr. Brown published a description of the process employed in extracting it from the mineral water, and in purifying it. (*f.*) In Italy it is manufactured from schistose minerals, containing sulphur and Magnesia." (*g.*) It exists in considerable quantity in sea-water; and the uncrystallized residuum in the salt-pans after all the common salt is crystallized, consists partly of this salt dissolved in water. This residuum is usually called *Bittern;* and sometimes, in Scotland, *Spirit of Salt.* (*h.*) In England that term is applied to hydrochloric Acid.

Sulphate of Magnesia is soluble in its own weight of water at 60° Fahrenheit; and a much less quantity if the water boils. When exposed to the air it is efflorescent; and by heat it is fusible; the water of crystallization is then gradually driven off, but the actual decomposition of the salt cannot be effected by any elevation of temperature. Thomson supposes the crystallized salt to contain seven atoms of water.

(539.) L. The most characteristic property by which the salts of Magnesia are recognised, is that by adding a solution of phosphate of soda; no precipitate is produced: but then if ammonia also be added, a white precipitate falls down, which is a double phosphate of ammonia and Magnesia. The delicacy of this test, which was pointed out by Dr. Wollaston, is so great, that an extremely minute portion of Magnesia may be detected by it. If the experiment be made in a watch-glass, it is advisable to rub the point of a glass rod against the surface of the glass within the solution. This aids the deposition, and the precipitate appears in white lines wheresoever the rod has passed.

Sulphate of soda occasions no precipitate in a magnesian salt, but the alkalis, or their carbonates, produce a white flocculent precipitate.

Prussiate of potash throws down no precipitate from a solution of any salt of Magnesia: those excepted which are formed by the metallic Acids.

(540.) M. Magnesia is largely employed in Medicine. The sulphate is a cooling purgative; and the carbonate, or the pure earth, is used as a purgative and antacid.

References to § 6.

(*a.*) Davy, *Phil. Trans.* 1808; (*b.*) *Thesis de Magnesia Alba;* (*c.*) *Obs. Phys. Chem.* 1722, p. 105 and p. 177; (*d.*) *Opusc.* vol. ii. p. 20; (*e.*) *Opusc.* vol. i. p. 365; (*f.*) Brown, *Phil. Trans.* vol. xxxii. p. 348; (*g.*) *An. de Ch.* vol. xlviii. p. 80; Gehlen, *Jour.* vol. iii. p. 549; Holland, *Phil. Trans.* 1816, p. 294; (*h.*) Thoms. *Syst.* vol. ii. p. 521.

METALS. CLASS II.

Sect. II.—*Calcium.*

(541.) A. This metal was one of the discoveries of Davy, made by means of the Voltaic battery.

(542.) B. It may be obtained by forming a paste of lime, or of sulphate of lime mixed with water into a cup, which is then to be placed on a metallic dish. Mercury is poured into the cup, and connected with the negative extremity of the pile; while, at the same time, the positive wire is made to touch the metallic dish. Thus in time an amalgam of mercury and Calcium is formed, and is to be put into a small retort, with a little naphtha to cover it. The retort is to be connected with a tubulated receiver loosely corked. By heat the naphtha rises in vapour so as to fill the vessels; the mercury next comes over; and the Calcium remains within an atmosphere of naphtha.

(543.) C. This Metal appears to have the colour and lustre of silver, but its other physical properties are unknown.

(544.) D. The instant that atmospheric air is admitted to Calcium, the Metal absorbs oxygen, and burns with an intense white light, again returning to the state of lime. Lime is the protoxide of Calcium. See subsect. 1.

(545.) A superior oxide of Calcium is formed by passing oxygen Gas over ignited lime; the Gas is absorbed, and this oxide results, but its exact atomic constitution is unknown.

(546.) E. If lime be heated in chlorine Gas, one volume of chlorine is absorbed, and half a volume of oxygen being evolved, the chloride of Calcium is formed. It is also produced by fusing hydrochlorate of lime at a red heat. By addition of water the hydrochlorate is again formed.

(547.) F. The substance to be hereafter mentioned as fluate of lime, is by some Chemists supposed to be a true fluoride of Calcium.

(548.) G. Iodide of Calcium is formed by evaporating hydriodate of Calcium to dryness, and fusing the residuum.

(549.) H. The existence of compounds of sulphur and phosphorus with Calcium seems to be sufficiently well established. The phosphuret is formed by taking a glass tube, fourteen inches in length, and one-third of an inch in diameter, closed at one end, and well coated with clay, excepting an inch at the closed end. Into this is put a drachm or two of phosphorus: the tube is then filled with fragments of fresh bûrnt lime as large as peas: the mouth of the tube may be loosely stopped with paper, and its body passed through a table furnace, and heated to redness. A spirit-lamp is then applied to the sealed end, so as to fuse and volatilize the phosphorus. The vapour passing over the heated lime decomposes it, and a phosphuret of Calcium results. This substance was long called phosphuret of lime: it forms an amusing experiment by dropping a small piece of it into a glass of water. In a short time, bubbles of phosphuretted hydrogen Gas rise through the water and explode on reaching the surface.

The sulphuret of Calcium was formed by Berzelius, who passed a current of sulphuretted hydrogen over red-hot lime. The hydrogen of the Gas united with the oxygen of the lime to form water, and the sulphur united with the Calcium.

(550.) I. Calcium would doubtless unite with other Metals; but this and many other of its properties have as yet been little studied.

Subsect. 1.—*Lime.*

(551.) A. The nature of this, the protoxide of Calcium, has been already explained in Art. (542.) It does not exist pure in Nature, from its great affinity for water and carbonic Acid. But, in the state of a carbonate, it forms one of the most abundant and important substances in Nature. Whole mountains and vast tracts of country consist of immense strata of this carbonate in various states of purity, and deposited at different epochs in the existence of our Earth. Hence it is that, as it is slightly soluble, there are few springs of water, however pure, that do not contain some Lime.

(552.) B. Lime is readily obtained by the calcination of common limestone, in which the water and carbonic Acid are driven off: but as this will contain an admixture of other earths and metallic oxides, it is necessary for chemical purposes to employ pure pellucid Iceland crystal, or the whitest Carrara marble. Oyster-shells also afford good Lime.

(553.) C. Lime is a white pulverulent earth, not fusible, save by the heat of the Voltaic pile, or of the Gas blow-pipe. Specific Gravity = 2.3. It is not volatile. With water it presents several singular phenomena. If this fluid be sprinkled on fresh caustic Lime, great heat is produced and the water entirely disappears, entering into combination to form a solid hydrate of Lime. Mr. Dalton estimates the heat produced on such an occasion at 800° Fahrenheit. Pelletier even states that light is evolved, so as to be seen in a dark place. Lime absorbs moisture from the atmosphere and falls to powder. This earth is slightly soluble in water, perhaps to about the extent of 1-700th part; 1-752d according to a careful experiment made by Mr. R. Phillips. Mr. Dalton has shown that in the case of Lime, cold water is capable of taking up more than hot water, as seen by the following Table:

	at 60°.	at 130°	at 212°
Grains of water to dissolve one grain of Lime	778	972	1270
Grains of water to dissolve one grain of hydrate of ditto	584	720	952

Lime-water possesses alkaline properties. When exposed to the air, the Lime unites with carbonic Acid and is precipitated. Gay Lussac, however, procured crystals of pure Lime, by placing a vessel of Lime-water with sulphuric Acid under an exhausted receiver. The crystals contained one atom of Lime + one atom of water. (*a.*)

(554.) D. None.

(555.) E. The combination of chlorine with Lime is one of great importance from its extensive application in the process of bleaching. If slaked Lime (the prothydrate) be passed through a sieve in the state of fine powder, and then placed in contact with chlorine Gas, the Gas is absorbed with great avidity, much heat being evolved. When the Lime has taken up all the chlorine that it is capable of, it appears a dry white powder, known in commerce by the names of bleaching powder, or oxymuriate of Lime.

It consists, in fact, of Lime, chlorine, and water; and probably in the proportions of 1, 2, and 6 atoms of these elements. This powder is, in fact, a subchloride of hydrate of Lime. Dr. Thomson calls it dichloride of Lime, but no one name has met with universal adoption.

This substance is soluble in water to a considerable extent. By heat it is decomposed; the water first passing off; then decomposition of the Lime takes place, oxygen Gas is evolved, and chloride of calcium is formed. The purity of this substance being of great importance, has engaged the attention of our most eminent Chemists, as will be seen from the reference. (*b.*)

(556.) F. G. Unknown or not existent.

(557.) H. With some of these substances Lime may be united, but the combinations are not of general importance.

It appears that by strongly heating Lime and sulphur some sulphuret of calcium is formed; but how far a true sulphuret of Lime exists is not quite certain, though long believed. If this sulphuret of calcium be dissolved in water, or if one part of sulphur, three parts of hydrate of Lime, and ten of water, be boiled together, a deep orange-coloured Liquid is formed, and has been much employed in eudiometry. By some it is termed hydroguretted sulphuret of Lime, but in our nomenclature it would be (408.) hydrosulphite of Lime. If a current of hydrosulphuric Acid Gas be transmitted through water, in which Lime is mechanically suspended, a *hydrosulphate* of Lime is formed, and may be separated as limpid crystals, soluble in water.

(558.) I. It is scarcely probable that any combination with these substances can be effected.

(559.) K. The Salts of Lime are numerous and important. Of these we can only name the sulphate, phosphate, and carbonate.

The sulphate is rapidly formed by art, and exists abundantly in Nature, known by the name of gypsum or plaster of Paris. By calcination it loses water, and the reabsorption, or addition of that Liquid, enables it to form an useful and cheap cement, or to take casts of gems and metals.

The phosphate forms to the amount of eighty-six per cent. a constituent of the bones of animals. The biphosphate, ter-phosphate, and quater-phosphate of Lime also exist, but Mr. Dalton considers the last an octo-phosphate.

The carbonate is the most abundant of the Salts of Lime. As chalk, limestone, and marble it must be familiar to every one. Although the affinity of carbonic Acid for Lime is very great, the substances do not readily combine, unless moisture be present. By a red heat the carbonic Acid is driven off from this salt in the Gaseous state; but if the escape of the Gas be prevented, Sir James Hall found that the limestone was fused by a heat of about 22° of Wedgewood's pyrometer (*c.*) This salt contains one atom of each of its proximate elements. A very elegant experiment by the late Professor Tenant of Cambridge, (*d.*) exhibits its ultimate decomposition. Carbonate of Lime is soluble in water, having an excess of carbonic Acid: hence arises the extensive calcareous deposit from the water of some springs. In these cases there exists in the water, carbonate of Lime dissolved in excess of carbonic Acid; by exposure to the atmosphere, the excess of carbonic Acid escapes, and the earthy salt is deposited.

(560.) L. Some of the Salts of Lime are soluble in water, others are not so. In such solutions no precipitate is produced by addition of pure ammonia; but potash and soda throw down caustic Lime. Upon solutions of Lime, the citrate or tartrate of ammonia produces no effect; but oxalate of ammonia exhibits a dense white precipitation. If an insoluble salt of Lime be boiled for some time in a solution of carbonate of potash, a white powder remains, consisting of carbonate of Lime, soluble with effervescence in nitric or muriatic Acid.

(561.) M. The uses of Lime are very various and important. The nitrate, when fused, forms Balduin's phosphorus. (*d.*) The chloride mentioned in Art. (555.) is now sold, when formed into an aqueous solution, under the name of Labaracq's Disinfecting Liquid; and is thus a convenient mode of applying the long known properties of chlorine for removing dangerous or disagreeable miasmata, in fever hospitals, or the chambers of the sick.

The use of gypsum in taking casts, and as a cement for marble or stone, has been already noticed. Caustic Lime is of great service in Agriculture when spread upon some kinds of land, as it ameliorates the stiff clays, and powerfully assists the solution of vegetable matters to form the food of growing plants. The formation of mortar from caustic, or quick Lime as it is called, for building, must be within the observation of every one. The mode of its operation is this. When fresh burned Lime is mixed with water, a paste is first formed, but, in a short time, the fluidity entirely disappears, by the passage of the water into the solid form to constitute dry hydrate of Lime. Some combination of carbonic Acid also takes place, but this is for the most part superficial. Lime made from the chalk or limestone of different strata, varies considerably in goodness. Such variations depend on the admixture of small proportions of certain other earths and oxides. The Roman cement, as it is called, contains a proportion of alumina and oxide of iron. On the subject of mortar there is a valuable Work by M. Vicat, in French.

References to § 1.

(*a*.) Gay Lussac, *An. de Ch. et Ph.* vol. i. p. 334. (*b*.) Dalton, *An. Phil.* vol. i. p. 15. and vol. ii. p. 6; Thomson, *An. Phil.* vol. xv. p. 401; Welter, *An. de Ch. et Ph.* vol. vii. p. 383; Ure, *Jour. Roy. Inst.* vol. xiii. p. 21; Gay Lussac, *An. Phil.* vol. viii. p. 218. (*c*.) Nich. *Jour.* vol. xiii. and xiv.; also Bucholz, vol. xvii. p. 229. (*d*.) *Phil. Trans.* vol. xi. p. 788. Consult also Davy, *Phil. Trans.* 1808, p. 333; and *An. Phil.* vol. iii. p. 360. Berzelius, *An. de Ch.* vol. lxxxi. p. 13.

Sect. II.—*Strontium.*

(562.) Strontium was first obtained by Sir H. Davy. Native carbonate of strontia was formed into a paste with water, and placed on a small platinum tray. A globule of mercury was then placed within a cavity made in the surface of the paste. The platinum was connected with the positive pole, and the mercury with the negative pole of a pile of about 100 double plates. Thus an amalgam of mercury and Strontium was shortly produced. The amalgam was introduced into a tube of glass made without lead, which was then filled with the vapour of naphtha, bent into the form of a retort, hermetically sealed. The mercury was then driven from the amalgam by heat, and the Strontium remained.

The lustre of Strontium is not considerable; it is difficult of fusion, and not volatile. It decomposes water with evolution of hydrogen Gas; and if exposed to atmospheric air, it again becomes strontia. This earth is then proved to be the oxide of Strontium; its properties will more fully be stated in the ensuing subsection.

Subsect. 1.—*Strontia.*

(563.) A. "About the year 1787, a mineral was brought to Edinburgh by a dealer in fossils, from the lead mine of Strontian in Argyleshire, where it is found imbedded in the ore, mixed with several other substances. It is sometimes transparent and colourless, but generally has a tinge of yellow or green. It is soft. Its Specific Gravity varies from 3.4 to 3.726. Its texture is generally fibrous; and sometimes it is found crystallized in slender prismatic columns of various lengths."

"This mineral was generally considered as a carbonate of barytes; but Dr. Crawford having observed some differences between its solution in muriatic Acid, and that of barytes, mentioned in his Treatise on *Muriate of Barytes*, published in 1790, that it probably contained a new earth, and sent a specimen to Mr. Kirwan that he might examine its properties. Dr. Hope made a set of experiments on it in 1791, which were read to the Royal Society of Edinburgh in 1793, and published in the *Transactions* about the beginning of 1794. These experiments demonstrate, that the mineral is a compound of carbonic Acid and a peculiar earth, whose properties are described. To this earth Dr. Hope gave the name of Strontites. (*a*.) Klaproth analyzed it also in 1793, and drew the same conclusions as Dr. Hope, though he was ignorant of the experiments of the latter, which remained still unpublished. Klaproth's experiments were published in Crell's *Annals* for 1793 (*b*.) and 1794. (*c*.) Kirwan also discovered the more interesting particulars of this new earth in 1793, as appears by his letter to Crell, though his dissertation on it, which was read to the Irish Academy in 1794, was not published till 1795. The experiments of these Philosophers were repeated and confirmed in 1797 by Pelletier, Fourcroy, and Vauquelin, (*d*.) and several of the properties of the earth still further investigated. To the earth thus detected, Klaproth gave the name of *Strontian* from the place where it was first found; and this name," with the omission of the final *n*, "is now generally adopted. Strontia is found abundantly in different parts of the World, and always combined with carbonic or sulphuric Acid." Thomson's *Syst.*

(564.) B. Pure Strontia is readily obtained by dissolving the native carbonate in nitric Acid, evaporating the solution till it crystallizes, selecting pure crystals, and driving off the nitric Acid by heat in a platinum crucible. Strontia contains strontium one atom + oxygen one atom.

(565.) C. Strontia thus obtained is a grey, pulverulent mass, having a violent affinity for water. By affusion of this Liquid, heat is evolved, and so much earth is dissolved that crystals separate on cooling. Dalton considers that these crystals contain twelve atoms of water + one Strontia. Strontia has alkaline properties, but, unlike barytes, it is not poisonous. (*e*.) The crystals of Strontia, when dissolved in alcohol, cause it to burn with a bright red flame.

(566.) D. By pouring an aqueous solution of Strontia into the deutoxide of hydrogen, a deutoxide of Strontia is formed.

(567.) E. If Strontia be heated in chlorine Gas, oxygen Gas is expelled, and a chloride of strontium is formed. The same takes place if hydrochlorate of Strontia be heated to redness.

(568.) F. G. Unknown, save that iodine decomposes Strontia, as chlorine does.

(569.) H. Action none very important, save that some of these bodies by aid of heat decompose the earth, and form sulphurets, phosphurets, &c. with its metallic base.

(570.) I. Not considerable.

(571.) K. Strontia never performs the part of an Acid; but with Acids it universally acts as a base. Its Salts are more soluble than those of baryta, but less so than those of lime. The greater part are capable of crystallization.

(572.) L. A solution of these Salts affords precipitates with the sulphates, phosphates, and oxalates; but not with ferro-hydrocyanate of potassa. Succinate of ammonia gives a precipitate in solutions of barytic salts, but none in those of Strontia. The colour of its flame in alcohol forms also a good test.

(573.) M. None, save to give colour in pyrotechnics. Strontia is not poisonous.

References to § 2.

(*a.*) *Edin. Trans.* vol. iv. p. 14. (*b.*) vol. ii. p. 189. (*c.*) vol. i. p. 99. See also Klaproth's *Beitrage*, vol. i. p. 260; and *Jour. de Mines*, No. 5. p. 61. (*d.*) *An. de Ch.* vol. xxi. p. 113. 276. (*e.*) Pelletier, *An. de Ch.* vol. xxi. p. 120. (*f.*) Gay Lussac, *An. de Ch.* vol. xci. p. 60.

Sect. III.—*Baryum.*

(574.) Such should be the spelling of this word, derived from βαρὺς, (heavy,) though we have at times inadvertently spelled it Barium, as is frequently done. This Metal was obtained by Davy in 1808, from the carbonate of baryta, by a process which we have already described in Art. (562.) with reference to strontium. The Metal has a dark grey colour, with a lustre inferior to that of cast iron. It is fused at a heat below redness; though solid at all ordinary temperatures. It did not rise in vapour till nearly a red heat, and then acted violently on the glass of the tube which contained it. By admission of atmospheric air or oxygen, it is converted into the earth baryta. (See subsect. 1.) It has been proved by Gay Lussac and Thenard to be capable also of uniting with an additional proportion of oxygen, so as to form a deutoxide, by passing oxygen Gas over pure baryta at a red heat. (*g.*) In the very curious experiments made with the Gas blow-pipe, by Professor Edward Daniel Clarke of Cambridge, he frequently reduced pure barytic earth to an appearance which himself and many Chemists regarded as the Metal Baryum. The quantities, however, so obtained were very small, and apparently superficial; insomuch that, beyond the appearance, no fully conclusive evidence of the reduction was afforded.

Subsect. 1.—*Baryta.*

(575.) A. "Barytes was discovered by Scheele in 1774; and the first account of its properties published by him in his Dissertation on manganese. (*a.*) There is a very heavy mineral most frequently of a flesh colour, of a foliated texture and brittle, very common in Britain, and most other Countries, especially in copper-mines. It was known by the name of ponderous spar, and was supposed to be a compound of sulphuric Acid and lime. Gahn analyzed this mineral in 1775, and discovered that it is composed of sulphuric Acid and the new earth discovered by Scheele. (*b.*) Scheele published an account of the method of obtaining this earth from ponderous spar. (*c.*) The experiments of these Chemists were confirmed by Bergman, (*d.*) who gave the earth the name of *terra ponderosa.* Morveau gave it the name of *Barote*, and Kirwan of Barytes; which last was approved of by Bergman, and is now" (with little change) "universally adopted. Different processes for obtaining Barytes were published by Scheele, Bergman, Weigleb, and Afzelius; but little addition was made to the properties ascertained by the original discoverer, till Dr. Hope published his experiments in 1793. (*e.*) In 1797, our knowledge of its nature was still further extended by the experiments of Pelletier, Fourcroy, and Vauquelin." (*f.*) Thomson's *System.*

(576.) B. Pure Baryta is best obtained by dissolving the native carbonate in diluted nitric Acid. This solution is to be evaporated so as to obtain crystals of the nitrate. These are decomposed by a red heat, leaving pure barytic earth. The atomic constitution of this oxide will be seen from the general Table in Part V.; and it may be well here to state, that from a wish to economize space, many statements of the same nature are not made under this reference, as they will all be found in the above-named Table.

(577.) C. Pure Baryta has a caustic taste; changes vegetable blues to green; and is capable of forming a soap with oils. As generally seen, it is fusible by a moderate heat, being a hydrate; but when obtained pure from the nitrate, it is so only under the most intense heat of furnaces or the Gas blow-pipe. Pure caustic Baryta is slaked by water, forming a hydrate with evolution of very great heat. If a solution of this earth be made in boiling water, and then allowed to cool slowly, regular crystals are produced. These contain Baryta one atom + water twenty atoms, according to Mr. Dalton.

(578.) D. When pure Baryta is heated to redness in oxygen Gas, a deutoxide of baryum is formed.

(579.) E. If pure Baryta be heated in chlorine Gas, a chloride of baryum is formed with evolution of half a volume of oxygen Gas for every volume of chlorine taken up. A similar substance is produced by heating hydrochlorate of Baryta to redness.

(580.) F. Unknown.

(581.) G. If the hydriodate of Baryta be heated to redness, an iodide of baryum is produced

(582.) H. No combination is known, or very probable, between Baryta and these substances, but in some cases, Baryta, if heated with them, produces such union with its metallic base.

(583.) I. It is not probable that the Metals can combine with Baryta, neither has it been found that even those which have the most powerful affinity for oxygen decompose it.

(584.) K. With Acids, Baryta combines as a base, forming an extensive class of Salts. Its sulphate and carbonate exist naturally among mineral bodies. The Salts of Barytes have, generally speaking, less tendency to dissolve in water than the Salts of lime have. The affinity between sulphuric Acid and Baryta, is extremely powerful, but the sulphate is decomposed by boiling it with solutions of the alkaline carbonates, or by fusion with them; but the former process is attended with some singularities. This Salt is also decomposed by heating it strongly with one-sixth of its weight of powdered charcoal. With phosphoric Acid, Baryta forms a phosphate and a biphosphate. For a good detailed description of the Barytic Salts, we must refer our readers to Thomson's *System*, vol. ii. p. 497.

(585.) L. The properties by which solutions of Baryta are recognised, are chiefly these. A solution of any sulphate produces a white precipitate insoluble in nitric Acid. Heat applied to one of its crystalline Salts, converts it into a carbonate, if the Acid be of a vegetable nature, but produces no change if the Acid be incombustible; or converts an hydrochlorate or iodate into a chloride or iodide of the metallic base. Prussiate of potash produces no precipitate in a Salt of Barytes, unless the Acid be one of the metallic class.

(586.) M. Baryta, or its Salts, may be considered at present useless, either in Medicine or in the Arts. Its action is, however, most powerful on the animal economy, as it is one of the most virulent poisons known.

References to § 3.

(*a.*) Scheele, vol. i. p 61 and 78, French Translation. (*b.*) Bergman's *Notes on Scheffer*, sec. 167. (*c.*) Crell's *Annals*, vol. iii. p. 3. English Translation. (*d.*) *Opusc.* vol. iii. p. 291. (*e.*) *Edin. Trans.* vol. iv. p. 36. (*f.*) *An. de Ch.* vol. xxi. p. 113 and 276. (*g.*) *Rech. Phys.* vol. i. p. 169.

Sect. IV.—*Lithium.*

(587.) This Metal was obtained by Sir H. Davy, and subsequently by Gmelin, from the newly discovered alkali, Lithia. (See subsect. 1.) It has never yet been seen in any considerable mass, partly from its rarity, and partly from the very great rapidity with which it returns to an oxidated state as fast as it is formed by the action of the pile.

Subsect. 1.—*Lithia.*

(588.) A. This alkali was discovered in 1818, by M. Arfwedson, a Swedish Chemist, engaged in the analysis of petalite, a mineral from the mine of Uto in Sweden. It has been subsequently discovered in spodumine, lepidolite, and in several sorts of mica. Its name, Lithia, is derived from λίθειος, (stony,) marking its origin as distinguished from that of the other two fixed alkalis, potash and soda.

(589.) B. Berzelius has suggested the neatest process for the separation of Lithia from earthy minerals. One part of the mineral finely powdered is to be intimately mixed with powdered fluor spar, and this mixture heated with three or four times its weight of sulphuric Acid, as long as any acid vapours are disengaged. Thus the silica unites with fluoric Acid, and passes off in the state of silico-fluoric Acid Gas, whilst the alumina and Lithia unite with the sulphuric Acid. These Salts are to be dissolved in water, and then pure ammonia is to be added, and boiled in the solution to precipitate the alumina. The Liquid is to be filtered and evaporated to dryness, and then the sulphate of ammonia may be expelled by a red heat. Sulphate of Lithia remains. This alkali is supposed to contain one atom of oxygen + one atom of Lithium.

(590.) C. Lithia has a white colour; is fused by a red heat, and in that state is transparent; it changes vegetable blues to green. It is not deliquescent when exposed to the air; is not so soluble in water as potassa or soda; and scarcely at all soluble in alcohol.

(591.) D. Unexamined.

(592.) E. Chloride of Lithium is formed when hydrochlorate of Lithia is heated to redness, and is a very deliquescent substance, and readily soluble in alcohol.

(593.) F. G. Unascertained.

(594.) H. Sulphur may be combined with Lithia, as with potassa and soda.

(595.) I. It would seem that Lithia is not entirely without action on the Metals, seeing that it corrodes a platinum crucible in which it may be heated.

(596.) K. With Acids, Lithia forms Salts like the other alkalis: but these have as yet been little examined. Its saturating power is higher than that of either potassa or soda. The Salts of Lithia are soluble in water, but the carbonate much less so than the other alkaline carbonates.

(597.) L. Hydrochlorate of platinum, ferro-hydrocyanate of potassa, and infusion of galls, produce no precipitate in Salts of Lithia. But a solution of carbonate of potash, added to a concentrated solution of a Salt of Lithia, produces a white precipitate. The phosphate of Lithia is also rather an insoluble Salt, in which respect it is distinguished from potassa and soda.

(598.) M. None at present known.

References to § 4.

Consult Arfvedson, *An. de Ch. et de Ph.* vol. x. p. 84; Gmelin, Gibb. *An.* vol. lxii. p. 339; Clark, *An. Phil.* vol. xi.; Vauquelin, *An. de Ch. et Ph.* vol. vii. p. 284; Gmelin, *An. Phil.* vol. xv. p. 341.

Sect. V.—*Sodium.*

(599.) This Metal was discovered by Sir H. Davy in 1807; and his experiments were detailed in the *Philosophical Transactions* of 1808. He found that if pure caustic soda, a substance to be described in the following subsection, were just moistened by merely breathing on it, and placed on a disc of platinum; the disc being connected with the negative pole of a powerful Voltaic battery, and a wire from the positive pole being brought in contact with the upper surface of the soda; decomposition gradually took place. Oxygen Gas was evolved at the positive wire, and globules of metallic Sodium appeared at the parts in contact with the platinum. (*a.*)

MM. Gay Lussac and Thenard subsequently discovered a process more purely Chemical, by which this alkali might be obtained (*b.*) in greater quantity. This is performed by heating soda and iron turnings to whiteness in a coated gun-barrel. The process has been slightly modified and improved by others, and full instructions may be obtained by consulting the Memoirs quoted in reference (*c.*)

(600.) Sodium at our ordinary temperatures is an opaque, metallic-looking Solid, having the lustre and nearly the whiteness of silver; but it is necessary to examine it when covered with a film of naphtha for the exclusion of atmospheric air. It is extremely malleable and ductile. It is lighter than water, having a Specific Gravity about .97. It is less fusible than potassium, but begins to lose its solid form at 120° Fahrenheit, and becomes fully fluid at 180° or 190°. It is not volatile even at the fusing heat of plate-glass. On being exposed to atmospheric air it soon unites with oxygen, and its surface becomes a stratum of soda; but in perfectly dry air it remains unchanged. It combines with oxygen Gas at ordinary temperatures slowly, and without ignition; at its fusing point the action is more energetic, but light is not evolved, unless the Metal itself be about red-hot. It decomposes water with effervescence and a hissing noise. In hot water this action is still more violent, but no flame is produced except from small particles, which may be driven off and ignited in their passage through the air.

Two or more oxides of this Metal are at present admitted by some. The first formed by fusing soda and Sodium together; in which case the oxygen seems to be shared between all the atoms of Sodium, and from this very circumstance it seems doubtful whether the grey substance so produced be a true definite compound or not. The next oxide, *soda*, is formed when Sodium is burned, a volume of air affording just oxygen enough to convert the Metal into an alkali. This seems to contain one atom of each of its elements; and in the state we usually possess it, there is also an atom of water which it retains with great obstinacy. But if the Metal be burned in excess of oxygen, another oxide is formed which appears to contain Sodium two atoms + oxygen three atoms. This substance is very fusible, and of a deep orange colour. When placed in water the excess of oxygen separates, and a solution of soda remains.

(601.) The chloride of Sodium is formed by burning the Metal in chlorine Gas; or by heating it in hydrochloric Acid Gas, in which case the hydrogen is set at liberty;—or by evaporating a solution of common salt, which in its crystalline form is a pure chloride of Sodium, having only a little water mechanically existent among its molecules. But when this substance (which is sometimes called a Salt inadvertently) exists dissolved in water, it is generally believed to be as a hydrochlorate of soda; and then is truly a Salt.

The chloride of Sodium, a most important and abundant substance, crystallizes in regular cubes: its varieties have been ably described by Dr. Henry. (*d.*) By heat it decrepitates, and then fuses into a solid mass. It dissolves in two and a half times its weight of water at 60° Fahrenheit, and hot water takes up very little more. Hence, as Dr. Henry well remarks, its solution crystallizes, not like that of nitre by cooling, but by evaporation. (*e.*)

(602.) Iodide of Sodium may probably be formed by a direct process, but it is certainly obtained by applying heat to the hydriodate of soda.

(603.) By heating Sodium in ammoniacal Gas, the hydrogen is disengaged, and an Iodide of nitrogen is formed. It unites also with sulphur, selenion, and phosphorus; but not with hydrogen.

(604.) Sodium may form alloys with all the Metals.

Its reagent action and useful applications, can only be sought for among the description of its oxides and Salts; save that the chloride (common salt) is a wholesome condiment to food, and a powerful antiseptic.

Subsect. 1.—*Soda.*

(605.) A. "Soda, called also *Fossil* or *Mineral Alkali*, because it was thought peculiar to the mineral kingdom, was known to the Ancients (though not in a state of purity) under the names of *νίτρον*, and *nitrum*. It is found in large quantities combined with carbonic Acid, in different parts of the Earth, especially in Egypt. But the Soda of Commerce is obtained from the ashes of different species of the *Salsola*, a genus of plants growing on the sea-shore; especially from the *Salsola Soda*, from which the alkali has obtained its name. The Soda of Commerce is also called *barilla*, because the plant from which it is obtained bears that name in Spain. Almost all the Algæ also, especially the Fuci, contain a considerable quantity of Soda. The ashes of these plants are known in this Country by the name of *Kelp*, in France by that of *Varec*.

"Soda and potash resemble each other so nearly, that they were confounded together, till Du Hamel published his dissertation on common salt, in the *Memoirs of the French Academy* for 1736. He first proved that the base of common salt is Soda, and that Soda is different from potash. His conclusions were objected to by Pott, but finally confirmed by Margraaf in 1758." Thomson's *System*.

(606.) B. It would occupy more space than we can here afford, to describe fully the processes for obtaining pure Soda from barilla; but an excellent abstract is given in Thomson's *System*, vol. i. p 326. The general features of it, however, may be collected from the process for potassa. (Art. 626.)

(607.) C. Soda when pure is a greyish white mass; highly attractive of moisture, and sufficiently caustic to corrode and dissolve the skin, or other animal matters. By exposure to air, however, it does not deliquesce like potassa, but absorbing water and carbonic Acid, it crumbles into a white powder.

(608.) D. None. E. See Art. (601.) F. Unknown. G. Unknown.

(609.) H. More remains to be discovered respecting the combinations of Soda with some of these bodies; that with sulphur has been examined, but its real nature is not very manifest. (*e.*)

(610.) I. Unimportant, though not absolutely nonexistent.

(611.) K. The Salts containing Soda as a base are numerous and important. The carbonate, bicarbonate, borate, (borax,) phosphate, and sulphate, are employed in Medicine and the useful Arts.

(612.) L. The solutions of Salts of Soda may be recognised by the following properties; they are all soluble in water, and in a higher degree than those of potassa. Their base is not precipitated by any reagent whatever. The form of the crystals will serve to distinguish them from those of a Salt of potassa. This is especially remarkable in the sulphate. By fusion in platinum-wire with the blow-pipe, a rich yellow colour is communicated to the flame.

(613.) M. Soda is largely employed in the very important arts of soap-boiling and glass-making.

References to § 5.

(*a.*) *Ph. Trans.* 1808. (*b.*) *Recherches*, vol. i. p. 74. (*c.*) Tennant, *Ph. Trans.* 1814; Mandel, *Camb. Phil. Trans.* vol. ii.; Thenard, *Traité de Chimie; An. Phil.* N. S. vol. vi. p. 233; Brunner, *Jour. Roy. Inst.* vol. xv. p. 279. (*d.*) *Phil. Trans.* 1810. For analyses consult Thomson's *Syst.* vol. i. p. 341. (*e.*) Figuier, *An. de Ch.* lxiv. p. 59.

Sect. VI.—*Potassium.*

(614.) A. This Metal was discovered by Sir H. Davy in 1807, and from its nature can only exist under peculiar artificial circumstances, or in combination with other elements.

(615.) B. To the process by which Potassium was obtained we have already adverted in the mention made of Sodium; (599.) for the same measures must be taken in procuring both Metals. As before, we must on this point refer our readers to the more ample details of original Memoirs. (*a.*)

(616.) C. At about 32° Fahrenheit it is hard and brittle, exhibiting a crystalline structure. At about 50° Fahrenheit it is a soft malleable solid, having the lustre of polished silver. At 70° Fahrenheit it is a semi-fluid substance, having in small globules a resemblance to mercury; but at 150° Fahrenheit it becomes quite fluid. At a heat about redness it may be volatilized unchanged. It is a conductor of heat and electricity. Its Specific Gravity has been variously stated from .8 to .9 referred to water as unity.

(617.) D. Potassium unites with oxygen, even though the Gas be dry, at ordinary temperatures; but by the aid of heat it burns therein with brilliancy. When the Metal is brought in contact with water, a violent action ensues; the water is decomposed with evolution of flame, and the protoxide of Potassium remains in solution. This protoxide is potassa. (See subsect 1.) But when Potassium is burned in the open air, or in oxygen Gas, it is converted into an orange-coloured substance, which is a superior oxide of the Metal. This is by some called the peroxide; we venture, in adherence to our system, to call it the tritoxide, to mark that it contains oxygen three atoms + Potassium one atom. The same substance is formed by passing oxygen Gas over potassa at a red heat. Potassa has a very strong affinity for water, so that even fused caustic potassa is a hydrate, containing potassa one atom + water one atom. But anhydrous potassa may be obtained by fusing nitrate of potassa in a crucible of gold. Mr. Dalton has given a Table showing the proportion of real alkali in solutions of potassa of different Specific Gravities. (*b.*)

(618.) E. If Potassium be heated in chlorine Gas, its combustion is more vivid than in oxygen; and a chloride of the Metal is formed. The same substance results from heating to redness hydrochlorate of potassa formed by dissolving carbonate of potassa in hydrochloric Acid; the hydrogen of the Acid uniting with the oxygen of the potassa to form water, which is dissipated by the heat.

(619.) F. Unascertained.

(620.) G. Iodide of Potassium may be formed by heating Potassium with iodine in a green glass tube. Light is evolved during the combination. This iodide is volatilized by heat; and by solution in water its elements take to themselves hydrogen and oxygen respectively from the water, and a solution of hydriodate of potash results.

(621.) H. With hydrogen, Potassium forms two compounds, the one gaseous, the other solid. The former is produced simply by heating Potassium in hydrogen Gas. The latter by a similar process, but at a very moderate heat. Potassium unites also with sulphur, selenion, and phosphorus.

(622.) I. Potassium has a great tendency to unite with many of the other Metals, especially with mercury; and the amalgam so formed is capable of dissolving all other metallic bodies.

(623.) K. In consequence of the strong affinity which this Metal bears for oxygen, it reduces the oxides of all other Metals when heated with them. When added to the mineral acids, Potassium decomposes water, becomes oxidized, and a salt of potassa remains in the solution.

(624.) L. M. All action to which this head refers, will more properly appear in the corresponding part of the subsection on potassa.

Subsect. 1.—*Potassa.*

(625.) A. " If a sufficient quantity of wood be burned to ashes, and these ashes be afterwards washed repeatedly with water till it come off free from any taste, and if this Liquid be filtered and evaporated to dryness, the substance which remains behind is *Potash:* not, however, in a state of purity, for it is contaminated with several other substances, but sufficiently pure to exhibit many of its properties. In this state it occurs in Commerce under the name of Potash. When heated to redness many of its impurities are burned off; it becomes much whiter than before; and is then known in Commerce by the name of *Pearlash.* Still, however, it is contaminated with many foreign bodies, and is itself combined with carbonic Acid Gas, which greatly modifies its properties.

" That Potash was known to the ancient Gauls and Germans cannot be doubted, as they were the inventors of soap, which Pliny informs us they composed of ashes and tallow. These ashes (for he mentions the ashes of the beech-tree particularly) were nothing else but Potash: not, however, in a state of purity. (*c*). The *κονία*, too, mentioned by Aristophanes and Plato, appears to have been a lie made of the same kind of ashes. The Alchymists were well acquainted with it; and it has been in every period very much employed in Chemical researches. It may be said, however, with justice, that till Berthollet published his process in the year 1786, Chemists had never examined Potash in a state of complete purity." Thomson's *System,* vol. i. p. 328.

Besides forming a part of many vegetable substances, Potassa is found in several animal fluids. Also in some minerals, as the leucite, lava, pumice, and in feldspar and zeolites, sometimes to the amount of eighteen per cent.

(626.) B. To obtain pure Potassa, take pearlash and dissolve it in twice its weight of hot water. To the solution add an equal weight of fresh-burned quicklime, slaked, and then formed into a cream with water. Boil these together in an iron kettle, for half an hour, continually stirring. Then filter out, or pour off the clear alkaline solution, and evaporate it to dryness in a silver capsule. Put the dry mass into a bottle, and add pure alcohol so as to dissolve out as much alkali as possible. Then separate again the alcohol by distilling it over from off the Potassa in a silver alembic with a glass head. Pour the fused residuum upon a silver capsule, and as soon as it is cool enough, let the cake be broken up and kept in well-closed phials. Potassa thus prepared is still a hydrate containing alkali one atom + water one atom.

(627.) C. Pure Potassa is a white, solid substance, highly caustic, fusible by a heat rather above redness, but not volatile. The solid hydrate has its apparent properties greatly similar. When quite dry it is a non-conductor of electricity.

(628.) D. If oxygen Gas be passed over Potassa in a closed tube at a red heat, an additional proportion of that element enters into combination, and the tritoxide of potassium is formed. We term it the tritoxide, as containing potassium one atom + oxygen three atoms, on the principles we have laid down for our guidance, (110.) &c.; but this substance has been hitherto called the deutoxide or peroxide, seeing that the combination of one atom of metal + two atoms of oxygen has not yet been recognised.

(629.) E. When chloride of potassium is dissolved in water, a solution of hydrochlorate of potassa results; and conversely when the latter Salt is evaporated to dryness, the metallic chloride is the only remaining product.

(630.) F. Little examined.

(631.) G. If iodine be agitated in a solution of Potassa, both an iodate and an hydriodate are formed; the latter being much the more soluble salt of the two.

(632.) H. The action of some of these bodies with Potassa is rather complicated, in some cases a union with the Potassa seems to be formed, in others the alkali is decomposed, and its metallic base forms the basis of the resulting compound. The hydrosulphate of Potassa, a useful test, is formed by passing a current of hydrosulphuric Acid Gas through a solution of Potassa; and it is capable of crystallization.

(633.) I. Potassa exerts a solvent action on some of the Metals.

(634.) K. With Acids Potassa forms, as a base, a most numerous and important class of Salts. *Nitre*, the nitrate of Potassa, is an anhydrous Salt, containing an atom of each of its proximate elements; when fused it is called *Sal prunella*. *Pearlash* and *Potash* of Commerce are carbonates of Potassa of variable degrees of purity. The proportionate composition of the carbonates of Potassa may be seen from the general Table in Part V. Sulphate of Potassa is employed in Medicine, and was formerly called *Sal Polychrest*. *Prussiate of Potash*, as it was long called, is the ferro-hydrocyanate, a delicate and useful test for distinguishing metallic solutions.

(635.) L. Potassa in solution is usually in the state of a Salt, it may be known by the following properties. The forms of the crystals. That a granular crystalline precipitate is produced by addition of tartaric Acid; by this it is well distinguished from soda. By not being precipitated by any preparation of nut-galls, nor by ferro-hydrocyanate of Potassa. By giving an orange-coloured precipitate with a solution of platinum in nitro-muriatic Acid: a property not possessed by soda or lithia.

(636.) M. Potassa in its various states performs several valuable services in Medicine and the Arts. Nitre is a powerful antiseptic, and an essential ingredient in common gunpowder. The alkali is used also in soap-boiling, glass-making, &c.

References to § 6.

(*a.*) Davy, *Phil. Trans.* 1808. Ritter, *An. de Ch.* vol. lxvi. p. 92; Gay Lussac and Thenard, *Mém. d'Arcueil*, vol. ii. p. 299; *Recherches*, vol. i. p. 74; *Phil. Mag.* vol. xxxv.; Tenant, *Phil. Trans.* 1814; Woodhouse, Nich. *Jour.* vol. xxi. p. 290; Curandau, Nich. *Jour.* vol. xxiv.; Bucholz, Nich. *Jour.* vol. xxix. p. 186; Murray, Nich. *Jour.* vol. xxviii.; *An. Phil.* N. S. vol. vi. p. 233; Brunner, *R. I. Journ.* vol. xv. p. 279. (*b.*) Henry, *Chemistry*, vol. i. p. 528. Ed. 10. (*c.*) Plin. *Hist. Nat.* lib. xviii. c. 51.

METALS. CLASS III.

Sect. I.—*Manganese.*

(637.) A. The most abundant ore of Manganese, the black oxide, has long been known; and very soon after the study of minerals assumed a scientific form, it was seen that a heavy, black, earthy substance, which had formerly been classed with iron-ores, must be separated from that genus. After several dissertations on this mineral, Bergman suspected it to be the oxide of a peculiar Metal, and at his desire Scheele undertook the examination of the substance, and by his Essay, published in 1774, and Bergman's of the same period, the metallic nature of its basis was established. This oxide is abundantly found in Devonshire and other parts of England: its other ores are the sulphuret, and a phosphate, wherein it is combined with iron, but these are rare.

(638.) B. From the great tendency of this oxide to vitrification, fluxes must not be employed for its reduction, an operation of great difficulty in consequence of the strong affinity of Manganese for oxygen. The only process by which the Metal has been obtained, is to submit oxide of Manganese, mingled with charcoal-powder and a little oil, to a most intense heat in a wind furnace. The Metal is fused in small globules, or in an imperfect button at the bottom of the crucible.

(639.) C. Manganese is of a greyish colour, and finely granular texture; softer than cast iron; Specific Gravity 8.013. (John.) It is very brittle, and of different fusibility. According to Morveau it melts at 160° Wedgewood, or at a point somewhat above iron.

(640.) D. Pure Manganese, being exposed to the air, gradually oxidates and crumbles into powder. If heated in oxygen Gas it undergoes combustion, and decomposes the vapour of water at a red heat. Perhaps there are few subjects of greater difficulty than the determination of the number of oxides which this Metal produces. We have on this subject valuable observations by Sir H. Davy, *Chem. Phil.* p. 367; John, *An. Phil.* vol. iii.; Berzelius, *An. de Ch.* vol. lxxxiii. and lxxxvii.; Gay Lussac, *An. de Ch. et de Ph.* vol. i.; Arfvedson, *An. de Ch. et de Ph.* vol. vi. Davy admits only two oxides, John three, Berzelius five, which number he has subsequently reduced to four; (*An. Phil.* vol. iii.) and according to Chevillot and Edwards, there is another degree of oxidation still higher than the peroxide of all former Chemists, and possessed of acid properties. (*An. de Ch. et de Ph.* vol. viii.) Thenard is inclined to admit four oxides including the one last mentioned, which exists in the chameleon mineral. In this state of uncertainty it is impossible in a sketch like the present to give even an outline of the processes or reasonings of these Chemists, we therefore must confine ourselves to the two oxides the existence of which is well established. The first is precipitated from the Salts of Manganese, in the state of a white hydrate, containing, according to Davy, about twenty-four per cent of water; when this water is driven off by a red heat the oxide assumes an olive-green colour.

The native black oxide, hitherto called the peroxide, which must be abandoned, should Chevillot and Edwards's experiments be verified, is familiar to every tyro in Chemistry, as the substance from which oxygen is principally procured. It is formed gradually by exposure of the olive oxide to the action of the air.

(641.) E. If metallic Manganese be exposed to heat in chlorine Gas their union is immediately effected, and light and heat are evolved. This chloride is a light, pink-coloured, flaky substance, and is obtained also by submitting hydrochlorate of Manganese to heat.

(642.) F. G. Unexamined.

(643.) H. Boron and silicon have not been united to Manganese. The phosphuret is easily obtained; and the carburet was found by Dr. Wollaston to constitute a peculiar substance filling small cavities in cast iron, and known in the foundries by the name of *keesh*. Bergman was able only to form a sulphuretted oxide of Manganese; but Vauquelin (*An. de Mus.* vol. xvii.) obtained the true sulphuret; and Proust has described a native compound of the same elements. With nitrogen and hydrogen no combination has been formed.

(644.) I. Many of the probable alloys of Manganese have not yet been examined. It has, however, been united with iron, copper, tin, zinc, gold, and arsenic. It refuses to combine with silver, mercury, or lead.

(645.) K. Until the number and composition of the oxides of Manganese shall be finally settled, our knowledge of the Salts of Manganese must remain in a state of great imperfection. It has been the opinion of Chemists that all the Salts which contain Manganese as a base, contain the green oxide: recent experiments, however, seem to prove that this is not the case; but it frequently happens that in processes wherein the solution of the black oxide is effected, certain phenomena occur which prove that the Metal, as it dissolves, is reduced to a lower degree of oxidation.

Nitric Acid dissolves Manganese with evolution of nitric oxide Gas. But on the black oxide, its action is extremely feeble. If, however, sugar, or any substance affording carbon, be added, solution takes place with evolution of carbonic Acid Gas; thus the excess of oxygen is disposed of, and a Salt containing the green oxide is formed. Nitrous Acid acts more readily, because the oxygen which the Metal loses, goes to form nitric Acid, and the same Salt is produced as in the former case.

Protosulphate. Sulphuric Acid has but little action on Manganese, but this Salt is readily formed by dissolving the carbonate in sulphuric Acid. It crystallizes in rhomboidal prisms which are soluble in alcohol.

Some other sulphates are mentioned by Arfvedson: one has been long known to be obtained by distilling sulphuric Acid off black oxide of Manganese, and lixiviating the residuum; the oxide contained in this reddish-coloured solution of the Salt is not well ascertained.

Scheele, by dissolving peroxide of Manganese in sulphurous Acid, found that some oxygen quitted the Metal and, uniting to the Acid, converted it into the sulphuric, and thus the protosulphate was formed. The true sulphite has not been obtained.

The hyposulphite remains in solution when hyposulphite of lime is precipitated by sulphate of Manganese.

The hyposulphate is an exceedingly soluble Salt, remaining in solution after the sulphate has been obtained by evaporation from the Liquid wherein sulphuric Acid has acted upon oxide of Manganese.

Hydrochloric Acid dissolves Manganese with evolution of hydrogen Gas; with the green oxide no Gas is evolved, but by its action upon the black oxide, chlorine is evolved. A solution thus formed contains hydrochlorate of Manganese, and this, by a proper heat, may be brought to the state of a chloride of the Metal.

Carbonate. A white powder precipitated from solutions of Manganese, by the addition of carbonate of potash.

Phosphate. This Salt occurs native, and, being scarcely soluble in water, is readily obtained artificially, by adding any alkaline phosphate to a solution of Manganese.

Seleniate. A soft, white, insoluble powder, fusible, and having the power of corroding glass. The biseleniate is soluble in water and crystallizable.

Arseniate. Formed by dissolving protoxide of Manganese in arsenic Acid. The Salt separates in a crystalline form. The addition of an alkaline arseniate to a solution of the Metal, produces the same effect. A double Salt may be formed by dissolving these crystals in sulphuric Acid. (John, Gehl. *Jour.* vol. iv. p. 443.)

Antimoniate. A white, insoluble powder, produced by adding an alkaline antimoniate to a neutral solution of Manganese. (Berzelius, Nich. *Jour.* vol. xxxv.)

Chromate. Chromic Acid acts slightly on Manganese, but this Salt is best obtained by dissolving the metallic carbonate in the Acid. A brown solution is formed which is not capable of crystallization. (John.)

Tungstate. This Salt is an insoluble, infusible, white powder, formed by adding tungstate of potash to a solution of Manganese. (John.)

Acetate. Acetic Acid acts feebly on Manganese and its carbonate. The acetate may be obtained by evaporation in pink crystals, soluble in water and alcohol. (John.)

Benzoate, or Benzoic Acid, has a similar action, and the Salt produced is in the form of slender, colourless, prismatic crystals, soluble in twenty times their weight of water, and also in alcohol. This Salt contains no water of crystallization.

Succinate. Manganese and its carbonate are readily soluble in succinic Acid. The crystals produced have different forms, and though singly they are transparent, yet a number of them together have a pink hue. They are insoluble in alcohol, but water dissolves eighteen per cent.

Oxalate. Oxalic Acid dissolves Manganese or its oxide with effervescence, and a white powder is precipitated. The same Salt is produced by adding oxalic Acid to a solution of the Metal in any Acid. (Bergman.)

Tartrate. An insoluble Salt, which is formed by adding a neutral tartrate to a solution of barytes. The Acid dissolves oxide of Manganese.

Citrate. The citric Acid dissolves Manganese, forming a Salt of moderate solubility.

Silicate. A beautiful rose-red ore of Manganese well-known to Mineralogists, is, according to Berzelius, a combination of silica and the metallic oxide, wherein the former earth performs the part of an Acid. (*Afhandlingar*, vol. i. p. 105.)

Double Salts.

Tartrate of potash and Manganese. By mixing tartrate of potash with a solution of Manganese; after some time has elapsed, small prismatic reddish brown crystals are deposited, consisting of this double Salt, which is sparingly soluble in water.

(646.) L. In neutral solutions of Manganese the following effects are produced. Fixed alkalis produce a white precipitate, which gradually blackens by exposure to the air. Prussiate of potassa and hydrosulphate of potassa a white precipitate. Hydrosulphuric Acid Gas whitens the solution, but produces no precipitate. Gallic Acid, infusion of galls, succinate and benzoate of ammonia, produce no effect; no other Metal throws down Manganese in the metallic state.

(647.) M. The common black oxide of Manganese is of great service to the Chemist for procuring oxygen; and it materially assists the glass-manufacturer in depriving glass of the green colour, which the iron present in the sand, or the flux, is liable to give to it. Bergman thus explains the theory of its action. Manganese in the state of black oxide produces a purple colour, but as a protoxide it gives no colour at all; iron, on the contrary, in a low state of oxygenation, gives a green tinge; but at a higher degree of oxidation it either remains infusible, or does not communicate colour. Hence it is evident that by these two oxides being present in proper proportions, each Metal passes to that state which is requisite for the formation of colourless glass. If the Manganese be in excess, the glass assumes a violet hue of any requisite intensity. Possibly, also, the oxygen of the Manganese may tend to the combustion of any carbonaceous matter present in the fused glass.

The black oxide of Manganese is largely employed in the preparation of chloride of lime for the bleachers.

For more ample details consult the references. (*a.*)

References to § 1.

(*a.*) Glauber, *Prosperitas Germaniæ;* Kaim, *de metallis dubiis,* 1770; Rinman, *Mem. Acad. Stockh.* 1765; Scheele, *Essays;* Bergman, *Opusc.* vol. ii.; John, Gehlen's *Jour.* vol. iii.; Berzelius, *An. de Ch.* vol. lxxxiii. and lxxxvii.; Arfvedson, *Jour. de Phys.* vol. lxxxvii. and *An. de Ch. et Ph.* vol. vi.; Chevillot and Edwards, *An. de Ch. et Ph.* vol. viii.; John, *An. Phil.* vol. ii.

Sect. II.—*Iron.*

(648.) A. This Metal, although the most abundant and useful of all with which we are acquainted, was probably not the earliest known to the inhabitants of the Earth. Gold, silver, and copper, frequently occurring native, would soon attract attention from their properties, and become valuable auxiliaries to the artificer; but with the exception of those rare masses which seem to be of meteoric production, Iron must have remained unknown until accident, or a suspicion of their nature, led to the reduction of its ores. This knowledge, however, the Israelites possessed in the time of Moses, but how or whence they obtained it we know not. History informs us that about 200 years afterward, its use was introduced into Greece; but two facts tend to prove that even after another period of two centuries, it was extremely rare in that Country. The first, that the weapons of war were formed of a hard alloy of copper and tin, or ancient bronze; and the second, that a ball of Iron formed a prize given by Achilles during the Trojan war. Throughout Europe, indeed, bronze probably preceded Iron in the fabrication of swords and the heads of spears. The Celtic inhabitants of Britain have left durable memorials of their workmanship in this beautiful alloy, and similar specimens have at different times been found in many of the Northern parts of Europe.

Some of the Salts of Iron occur native, but it is from the oxides that the Iron of Commerce is principally obtained; the sulphurets are also frequent. As a genuine mineral production, native Iron is of great rarity.

(649.) B. The reduction of the ores of this Metal on the large scale will come under consideration elsewhere, and for Chemical purposes the best soft Iron is to be selected, which is nearly pure, but may contain a little carbon, from which indeed this Metal is seldom entirely free.

(650.) C. The bluish-white colour of Iron is familiar to every one. Its hardness when pure is not very great; but when converted into steel, it may be rendered superior in hardness to almost every other substance. It is malleable when cold, and more so when hot, but in this respect it is inferior to gold and silver, though much superior to either in ductility. Its tenacity is great, and its Specific Gravity is stated from 7.6 to 7.87. Its fusing point is about 158° of Wedgewood. (M'Kenzie.) It is capable of permanent magnetism; but when pure it does not long retain this property. When Iron is violently heated its surface softens, and if two pieces in this state be hammered together a perfect union is effected. This property is common only to this Metal and platinum: it is of great utility, and known to artificers by the term *welding.*

(651.) D. Iron has an exceedingly strong affinity for oxygen; it rusts, that is oxidates, by free exposure to the atmosphere, and this effect is greatly accelerated by moisture. It gradually decomposes water also at ordinary temperatures; but some recent experiments of Dr. Hall (Brande's *Journal*) render it probable that this effect will not take place in pure water when the access of air is prevented. At a red heat it decomposes water with great rapidity; at a very intense heat it decomposes the fixed alkalis; but it is a singular circumstance, that though in the first case it takes oxygen from hydrogen, and in the second from the metallic bases, yet hydrogen and these bases are also capable of decomposing the oxides of Iron. Thus a curious problem in affinity is presented.

Two distinct oxides of Iron are recognised by all Chemists, the black and the red. The first has long been known as the *Martial æthiops* of the Materia Medica. It is best formed by exposing a paste of iron filings and water to the action of the air, moistening it repeatedly till the whole is oxidated, and then drying the powder by a gentle heat in an iron vessel. (De Roever, *An. de Ch.* vol. xliv.) The same oxide is precipitated from recently prepared sulphate of iron, by the addition of pure potash; and also by the combustion of iron wire in oxygen Gas. The red (per) oxide is formed by exposing iron filings to a red heat in an open vessel; a deep-red powder is produced, formerly termed *Saffron of Mars.*

Thenard and Gay Lussac have described other oxides of Iron, but at present considerable uncertainty exists on this subject. The atomic constitution of the oxides of Iron presents difficulties which have not yet been satisfactorily removed.

(652.) E. The chloride of Iron was discovered by Dr. J. Davy; it is obtained by dissolving the Metal in hydrochloric Acid, evaporating and exposing the residuum to a red heat, carefully excluding atmospheric air.

Thus obtained, the protochloride is of a grey colour and metallic lustre, fusible, but not volatile, and imperfectly soluble in water. (*Phil. Trans.* 1812.)

The deutochloride is obtained by burning Iron wire in chlorine Gas, or by evaporating an hydrochloric solution of the red oxide of Iron to dryness, with exclusion of atmospheric air. The substance is fusible, volatile, and may be condensed in minute crystals. It is soluble in water. (Sir H. Davy, *Phil. Trans.* 1811, and Dr. J. Davy, *Phil. Trans.* 1812.)

No analysis of these two compounds has a very strict agreement with the theoretical composition, supposing the former to consist of an atom of each substance, and the latter of one atom of Iron and two atoms of chlorine.

(653.) F. Unknown.

(654.) G. The only iodide of this Metal at present known, is formed by heating Iron in the vapour of iodine. It is a brown, fusible substance, soluble in water, producing a light green solution.

(655.) H. Of the combinations of Iron with combustibles, the carburets are by far the most important. When the Metal is in excess, steel is formed of different kinds, in proportion to the quantity of carbon; and it is stated by Mr. Mushet that no good steel contains more than one-sixtieth of carbon. In cast Iron, however, a greater proportion is found, the maximum of which is stated at one-fifteenth. For further particulars on this branch of manufacture, see reference (*b.*) Carbon, combined with a very small proportion of about one-twentieth, is the native plumbago, formerly called black lead. With regard to all the combinations of carbon and Iron, no satisfactory attempt can be made to bring them under the laws of the atomic theory; true Chemical combinations they nevertheless appear to be; and if so, the atom of one element must be united to more atoms of the other than we are in the habit of considering probable from the known constitution of other bodies. The phosphuret of Iron may be formed artificially, and also enters into the composition of what is termed *cold short Iron.* According to Berzelius the silicuret and seleniurets exist, and the boruret has been described by Gmelin. Two definite sulphurets exist native, the one known as magnetic pyrites, the other having so much sulphur that the magnetic property is destroyed. According to Mr. Hatchett, whose experiments are highly interesting, the carburets, sulphurets, and phosphurets of Iron have each some particular properties of combination, at which magnetism is most powerfully and permanently developed. Pure Iron being capable of little permanency in its magnetism, and again, when combined with too great a proportion of the nonmetallic combustible, losing the property altogether.

(656.) I. Strictly speaking, Iron may be considered capable of uniting with all the other Metals, though some of these combinations are of difficult formation: thus the great infusibility of both the Metals renders it difficult to form an alloy of platinum and Iron; and the volatility of mercury at a comparatively low temperature presented an obstacle to its union with Iron. This difficulty, however, Mr. Aikin indirectly surmounted.

(657.) K. The black oxide is soluble in most Acids forming light green solutions. The red oxide gives also, with most Acids, solutions of a reddish-brown colour, but is not so readily soluble as the black oxide. There exist then two distinct series of the Salts of Iron with the same series of Acids, *viz.* the protosalts and the persalts, as for the present we may continue to call them.

Nitric Acid (Specific Gravity 1.16) acts gently upon Iron with very slight evolution of Gas, and a solution of protonitrate of Iron remains, darkly coloured by the nitrous Gas, which the Liquid at first retains, but which by combining with oxygen is gradually converted into nitric Acid, and becomes transparent.

If the above protonitrate be exposed to the air, or heated, it passes into the pernitrate, which is also the Salt obtained by the action of strong Acid upon the Metal; in this case a rapid decomposition takes place, and the protoxide and deutoxides of azote are abundantly evolved. This Salt is decomposed by a red heat, the red oxide remaining no longer soluble in nitric Acid. Hence, in analysis, if it be desirable to estimate the Iron in the state of protoxide, a few drops of nitric Acid are added previous to exposure to a red heat; but if the protoxide be required, the residuum is mixed with a little tallow or wax, and by exposure to a gentle red heat, a definite protoxide is obtained.

It is well to remember that the protoxide is soluble in nitric, but not in hydrochloric Acid. The peroxide is soluble in hydrochloric Acid, but not in nitric. No crystals of the pernitrate can be obtained by evaporation, but Vauquelin is said to have formed them indirectly.

Sulphuric Acid dissolves Iron and both its oxides. By the action of dilute Acid upon the Metal, hydrogen is evolved, and the protosulphate is produced. It is readily crystallized, but both in this state and in solution, if exposed to the air, the Metal proceeds to a higher degree of oxidation. This Salt is well known by the names of *green vitriol* or *copperas;* that which is met with in Commerce is chiefly produced by moistening native pyrites, with exposure to air and subsequent washing, evaporation, and crystallization. In the crystalline state, this Salt contains about forty-five per cent of water.

There are, according to Thomson, three subspecies of persulphate of Iron, but want of room will compel us here to refer to his system for a more particular account of them. The red persulphate of Iron being soluble in alcohol, which the green protosulphate is not, affords a ready mode of separating these Salts if mixed. The sulphite of the protoxide only is known, and may be formed by direct solution of the base in the Acid.

By the action of sulphurous Acid on Iron, the hyposulphite is produced, and its formation, as explained by Berthollet, is exceedingly instructive. The mutual action is violent, but no Gas is evolved. The Iron is oxidized at the expense of the Acid; half its oxygen combining with the Iron to form the black oxide, while the remaining sulphur and oxygen form hyposulphurous Acid, which unites with the base. (*e.*) Mr. Herschel obtained the same Salt by dissolving carbonate of Iron in sulphurous Acid, and boiling the solution upon sulphur. (*f.*) The protomuriate is formed by the action of muriatic Acid upon metallic Iron, but the *protoxide is insoluble in this Acid,* while by its action upon the *peroxide* the soluble permuriate is readily obtained.

A solution of fluoric Acid in water dissolves Iron; the solution does not crystallize by evaporation, but only becomes gelatinous.

A solution of carbonic Acid in water acts feebly upon Iron; with excess of Acid the Salt remains dissolved, but by boiling, or by long exposure to air, the Iron falls down in the state of red oxide, still retaining some Acid; this process is daily seen in mineral waters. The carbonate has recently been found native, (*c.*) and may also be obtained by precipitating a solution of the sulphate by an alkaline carbonate. The rust which collects on exposed surfaces of Iron, especially if moist, is this carbonate more or less perfect.

The phosphate is produced by mixing solutions of phosphate of soda and sulphate of Iron, the perphosphate by mixing those of permuriate of Iron and phosphate of soda; it exists also native. (*d.*)

The borate precipitates, by the addition of solution of borate of soda to that of sulphate of Iron. Berzelius has described (*An. de Ch. et de Ph.* vol. ix.) the protoseleniate and biprotoseleniate, the perseleniate and biperseleniate. (*g.*)

The protarseniate and perarseniate of Iron exist native in Cornwall; the former may be produced by adding arseniate of ammonia to a solution of sulphate of Iron, and the latter by adding the same arsenical Salt to a solution of persulphate of Iron. Antimoniate of potash precipitates a white antimoniate of Iron from the sulphate. Chromate of potash produces from sulphate of Iron a tawny-coloured precipitate, consisting of oxide of chromium. Hence Vauquelin observes, that as the black oxide of Iron decomposes chromic Acid, protochromate of Iron does not exist. (Vauquelin, *An. de Ch.* vol. lxx.) He suggests that we might probably form a perchromate by employing some persalt of Iron instead of the protosulphate.

Alkaline molybdates, according to Scheele, produce a brown precipitate in the Salts of Iron. The tungstate exists native, (Wolfram,) and may be formed by adding an alkaline tungstate to a solution of sulphate of Iron. Acetic Acid readily dissolves Iron, and appears to form distinct Salts with the two oxides. The acetate is crystallizable, but the peracetate by evaporation is only gelatinized. The benzoate of Iron is a yellow, insoluble Salt, obtained by precipitation. The succinate is a crystallizable Salt, obtained by dissolving oxide of Iron in succinic Acid. But by adding succinate of ammonia to solutions of the persalts of Iron, a reddish, insoluble persuccinate is thrown down. On this property is founded one method of separating Iron from manganese. Thus by taking care to have the mixed solution of the Metals neutral, and the Iron in the state of a persalt, and then adding succinate of soda, the Iron may be entirely precipitated. By adding boletate of ammonia to a protosulphate of Iron no precipitate is produced; a solution of persulphate is entirely decomposed by these means, and the Iron thrown down in the form of a red powder. According to Braconnet, by this means Iron may be separated from manganese, lime, or alumina.

Sulphuric Acid gives a deep yellow colour to sulphate of Iron, but causes no precipitation. Oxalic Acid dissolves both Iron and its oxides; the protoxalate is soluble and crystallizes; the peroxalate has the contrary properties. The superoxalate of potash is, therefore, sold under the name of *Salt of lemons*, for the purpose of removing spots of ink from linen. From a persalt of Iron, mellitic Acid produces a yellow precipitate. Iron and its oxides are soluble in tartaric Acid; the prototartrate is soluble and crystallizable; the pertartrate has not these properties. Citric Acid dissolves Iron, and gradually deposits a white powder, which is stated to consist of a citrate and a bicitrate of Iron: the former readily passing, if exposed, to the state of percitrate, which is a deliquescent and soluble Salt.

According to Scheele, the saclactic Acid does not throw down Iron from its sulphate. Malic Acid gives, according to Scheele, a brown, uncrystallizable solution. Lactic Acid dissolves Iron, depositing delicate crystals, scarcely soluble in water. With protosalts of Iron, gallic Acid produces no precipitate, but with the persalts it forms the well-known black of our writing-ink; and this, though in reality a true precipitate of pergallate of Iron, is in so minute a state of division, as to remain suspended in the Liquid, especially if its consistency be increased by the presence of any mucilaginous substance.

Double sulphates of potash and Iron, and potash and ammonia exist. (Link, *An. de Ch.* vol. l.) The well-known tartarized tincture of Iron of the Materia Medica, is a double tartrate of potash and Iron. And the *Ferrum Ammoniatum* of the Pharmacopœia, is a double muriate of ammonia and Iron formed by sublimation. In this case the ammonia and the Acid are capable of carrying the oxide of Iron along with them in the volatile state, and the same property enables the muriatic Acid to carry over with it Iron in the process of distillation, which is the cause of the yellow colour in the common Acid of Commerce.

On a review of the above Salts of Iron it will appear, that for the most part the protosalts are crystallizable, and that the greater part of them are so soluble as not to be obtained by precipitation; that is supposing the formation of a protosalt to take place when a neutral solution of any Salt is added to a protosalt of Iron, the newly-formed Salt remains in solution; but whether this is the case, or whether no decomposition is effected, we have not at present any means of determining.

The persalts, on the contrary, rarely crystallize, and generally fall down in an insoluble state.

(658.) L. Much of the effects of reagents on the solutions of Iron, may be gathered from the preceding section. The most common tests of Iron are the infusion of galls, which gives no precipitate until the Iron is peroxidized by a few drops of nitric Acid, or by exposure to the air. The ferro-hydrocyanate of potassa giving a white precipitate with the protosalts, and a deep blue one with the persalts, is a most delicate test. Sulphuretted hydrogen produces no precipitate with the protosalts, but with the persalts gives a precipitate consisting of sulphur, because in this case the sulphuretted hydrogen is decomposed, and also the peroxide of Iron, which passes to the state of protoxide. "This Gas likewise precipitates Iron from its solution in some of the weaker vegetable Acids." Hydrosulphuret of potash gives a black precipitate with the persalts.

(659.) M. The countless uses of metallic Iron and steel need no enumeration; two of its Salts have been mentioned as employed in Medicine, and formerly it was given in several other states of combination. The peracetate is of great use to dyers, and considerable quantities of the sulphate are employed by hatters.

References to § 2.

(*a.*) Lavoisier, *An. de Ch.* vol. i.; Bergman, *Opusc.* vol. iii.; Vauquelin, *An. de Ch.* vol. xxii.; Morveau, *Ibid.* vol. xxxi.; Proust, *An. de Ch.* vol. xxiii.; Thenard, *An. de Ch.* vol. lvi.; Hassenfratz, *An. de Ch.* vol. lxix.; Bucholz, Gehl. *Jour.* vol. iii.; Berzelius, *An. Phil.*

ii. or *An. de Ch.* vol. lxxviii.; Gay Lussac, *An. de*
rol. lxxx.; Meyer, Crell's *An.* 1784; Hatchett,
Trans. 1804; Proust, *Jour. de Phys.* vol. liii.
Steel, Stodart on Tempering, Nich. *Jour.* 4to. vol.
Davy, *An. Phil.* vol. i.; Pearson, *Phil. Trans.*
; Scheele on Plumbago, *Essays*; M'Kenzie, Nich.
4to. vol. iv.; Berzelius, *Afhandlingar*, vol. iii.;
r, *Manchester Mem.* vol. v.; Clouet on Steel,
de Mines, 1799, also *Jour. de Mines*, vol. iv.;
on and Darcet on Steel, *Jour. de Mines*, 1798;
et on Steel, *Phil. Mag.* vol. xii. and xiii. (*c.*)
olz, Gehl. *Jour.* vol. i. (*d.*) Laugier, *An. de Ch.*
(*e.*) Berthollet, *An. de Ch.* vol. ii. (*f.*) Herschel,
st. *Jour.* vol. i. (*g.*) Berzelius, *An. de Ch. et de*
ol. ix.

Sect. III.—*Tin.*

0.) A. Pliny begins his chapter upon Tin thus,
um illitum æneis vasis, saporem gratiorem facit,
mpescit æruginis virus; mirumque, pondus nil
(Mirum! truly.) He describes it as coming
Spain and Britain, and mentions its great abun-
in the latter. (*a.*) Moses mentions Tin as one
Metals that may "abide the fire" for purifica-
b.) The mines of Cornwall, from which great
ities of this Metal are procured, exceed in richness
of every other part of the world; but the purest
s said to come from the Peninsula of Malacca.
principal ore of Tin is its oxide, under various
lline forms, which have been ably investigated by
. Phillips. (*c.*) As a sulphuret it is also found,
is is a rare mineral, and largely contaminated
opper.

1.) B. The common process for smelting Tin in
all is fully described in Aikin's Dictionary; it
ts in pulverizing the ore, and washing it so as to
e the lighter rocky particles. The heavy metalli-
ones which remain, are then roasted to drain off
and sulphur, and to oxidate some other metallic
ities. By a subsequent washing, the oxide of Tin
is in tolerable purity; it is now mixed with
al, and subjected to a violent furnace heat, by
the reduction is effected, and metallic Tin sub-
to the bottom of the furnace, from which it is
into pigs for sale.

.) C. Tin is of a brilliant white colour; it has a
but disagreeable taste, and emits a smell when
. In hardness it is superior to lead, but inferior
; Specific Gravity 7.291 to 7.299. "It is very
ble: Tin-foil, as it is called, is about one-thou-
of an inch thick, and it might be beaten out into
as thin again if wanted for purposes of Art. Its
y and tenacity are much inferior to that of most
Metals known to the Ancients." A wire one-
f an inch in diameter is calculated just to support
ht of 47.36 pounds. Tin is very flexible, and a
r crackling noise is heard on bending it; the
ty is peculiar to this Metal and cadmium. Tin
t a temperature of 442° Fahrenheit, but requires
high temperature for its volatilization. By
cooling, the crystals obtained from this Metal
mboidal prisms. (*d.*)

.) D. By exposure to air Tin becomes tar-
but undergoes no further change; at ordinary
atures it has no action upon water, but if steam is
over Tin heated to redness, a rapid decomposition is effected, the Tin is oxidated, and hydrogen is given out. (*e.*) Of this Metal there are two distinct oxides. The first, or grey oxide, is produced by dissolving Tin in hydrochloric Acid, with aid of heat, and precipitating the solution by ammonia. Thus an hydrate of the protoxide is obtained. By heat it is not decomposed, but passes to a higher degree of oxidation; it is soluble in alkalis and Acids.

The deutoxide is obtained by acting upon Tin with concentrated nitric Acid; no solution is effected, but a white powder is formed, which is a hydrate of the deutoxide. By heat, the water is driven off, and the pure yellow deutoxide remains. Berzelius obtained the same substance by heating Tin-filings in contact with peroxide of mercury. (*f.*)

This oxide may, by digestion, be united to the sulphuric and muriatic Acids; but though in both cases the compound remains insoluble in the Acid, yet in the former it becomes soluble in water. In the same manner, by digestion with alkalis, compounds soluble in water are similarly produced.

The two oxides of Tin are easily distinguished from each other by their properties: the protoxide undergoes evident combustion, at a red-heat; the deutoxide does not so. The former is soluble in dilute nitric Acid; the latter is not so. The former deflagrates with nitre; the latter does not so. Solutions of the protoxide gives black precipitates with corrosive sublimate.

(664.) E. Two chlorides of Tin are described by Dr. J. Davy. (*f.*) The protochloride is most easily obtained by heating protomuriate of Tin in a retort, till a fused, grey, resinous substance remains.

The deutochloride may be formed by heating Tin, or its protochloride, in chlorine Gas; but it is most readily formed by heating 6 parts of Tin, 1 of mercury, and 33 of corrosive sublimate, together in a retort. At first, water is disengaged, but afterwards a white vapour is rapidly produced, and condensed in a receiver, forming a colourless Liquid. This has long been known by the name of the *fuming liquor of Libavius*, from its discoverer.

(665.) F. Unexamined.

(666.) G. Tin in fusion readily combines with the vapour of iodine, and a fusible, orange-coloured iodide is the result. Water converts it into hydriodic Acid and oxide of Tin.

(667.) H. Tin, in all probability, does not combine with hydrogen nor azote; neither has its union with carbon, boron, or silicon been effected. The phosphuret may be formed by dropping pieces of phosphorus into melted Tin, or by fusing in a crucible equal parts of glacial phosphoric Acid and Tin-filings.

Three sulphurets of Tin are known to Chemists. The proto-sulphuret is formed by fusing Tin and sulphur together, pulverizing the compound, again mixing it with sulphur, and subjecting it to a sufficient heat to volatilize all the superabundant sulphur. This compound has metallic lustre with the colour of lead, and is capable of crystallization. "When dissolved in concentrated muriatic Acid it is entirely converted into oxide of Tin and sulphuretted hydrogen Gas." Thomson.

A substance, long known to Chemists under the name of *Aurum Mosaicum*, is the deuto-sulphuret of this Metal. The best process for obtaining it appears to be as follows. Amalgamate 8 oz. of Tin with an equal quantity of mercury, mix this with 6 oz. of sulphur and 4 of muriate of ammonia. Expose this compound to a violent heat in a matrass, and on breaking the matrass, beautiful hexagonal plates of the *aurum mosaicum* will be found condensed within the neck of the vessel. This substance is in the form of delicate scales, which have the appearance of gold, and if applied with varnish to any smooth surface, may be made to acquire considerable beauty from the operation of the burnisher.

The other sulphuret of Tin was obtained by Berzelius, who distilled deutosulphuret of Tin with sulphur; and obtained what has been called a sesquisulphuret, but is in our nomenclature a hemideutosulphuret of Tin.

(668.) I. Tin appears, as far as trial has been made, to be capable of uniting with every Metal; producing greater or less change in their mutual properties. With potassium, sodium, cobalt, arsenic, brittle alloys are formed. With bismuth, zinc, and lead, the alloys have considerable ductility and tenacity. Iron does not combine readily with Tin, but by fusing the Metals, in a closed crucible, an alloy is formed. According to Bergman (*h.*) two distinct alloys, containing widely different proportions of the Metals, are found after fusion in the same crucible, the one of 21 Tin + 1 iron, the other of 1 Tin + 2 iron; this is a question worthy of examination.

(669.) K. The Salts formed by the oxides of Tin are exceedingly curious, and have important properties.

Diluted nitric Acid (Specific Gravity 1.114) dissolves Tin with effervescence, and it is recommended to moderate the violence of the action by plunging the vessel in which the process is carried on into cold water. Thus a solution of protonitrate of Tin is obtained. By standing, and especially if heat be applied, a portion of the protoxide is deposited; the solution also contains nitrate of ammonia, for in the process both nitric Acid and water are decomposed, and by the union of the nascent azote of the one, and the hydrogen of the other, the alkali is generated.

If, however, strong nitric Acid (Specific Gravity 1.25) be poured upon Tin-filings, the action is exceedingly violent, and the Metal being oxidated *ad maximum*, is entirely precipitated in the state of a white powder; thus pernitrate of Tin cannot exist. In this case, also, ammonia is produced. This interesting experiment may be performed by adding a small quantity of strong nitric Acid to Tin-foil, or Tin-filings, in a Wedgewood mortar, and after the first violence of the action has ceased, and the fumes of nitrous Gas are chiefly dispersed, add a little caustic alkali or quick-lime; on rubbing the mixture together a pungent smell from the disengaged ammonia is perceptible.

By the action of cold sulphuric Acid on this Metal, the Acid is decomposed, sulphurous Acid Gas is evolved, and a persulphate of Tin is fully held in solution; by evaporation, this Salt gelatinizes, but does not crystallize; and by affusion of water, it is separated in the form of a white powder.

By solution of the protoxide of Tin in this Acid, a crystalline protosulphate may be formed.

If a plate of Tin be placed in sulphurous Acid, a black powder gradually falls, which is sulphuret of Tin, produced by the partial decomposition of the Acid; while at the same time a part of the Tin is oxidated, and hyposulphite of Tin remains in solution. According to Herschel, also, this hyposulphite is a soluble Salt, as mere Tin causes no precipitate in an alkaline hyposulphite.

Hydrochloric Acid readily dissolves Tin, with evolution of a fetid hydrogen Gas. In this solution the Metal is in the state of protoxide, and from the strong tendency which Tin has to pass to the higher degree of oxidation, this solution produces marked effects in many metallic solutions, wherein the oxygen is combined with the Metal by a feeble degree of affinity. Thus by protohydrochlorate of Tin, solutions of zinc, antimony, silver, and mercury, are precipitated in the metallic state, either pure or mixed with some portion of Tin. With gold a purple precipitate is produced, containing both gold and Tin in some state of combination, not at present clearly understood. The persalts of iron are reduced to the state of protosalts. For many more of these important properties we must refer to the Memoirs of Pelletier and Proust. This protohydrochlorate may be crystallized, but readily changes to the state of deuthydrochlorate, if great care be not taken to preserve it from oxygen. The deuthydrochlorate may be formed by dissolving the deutoxide of Tin in muriatic Acid, or by the process before given for obtaining Libavius's liquor, in which state it has been already described.

From the failures of Bergman (*i.*) and Proust (*k.*) it would appear that no carbonate of Tin can exist.

Phosphate of Tin being insoluble in water, is formed by adding hydrochlorate of Tin to an alkaline phosphate, but liquid phosphoric Acid has scarcely any action on metallic Tin.

Precisely similar properties mark the action of boracic Acid. Arsenic Acid is slowly decomposed if digested upon Tin; but by adding this Acid to acetate of Tin, or by mixing alkaline arseniates with muriate of Tin, an insoluble arseniate of Tin is precipitated.

With the assistance of heat, acetic Acid acts slowly upon Tin; and both the protacetate and deutacetate seem to have been formed; the first capable of crystallization; the second only capable of gelatinization.

Benzoic Acid does not dissolve Tin or its oxides, but by adding benzoate of potash to a solution of Tin a benzoate of Tin is precipitated. It is soluble in hot water, but insoluble in alcohol.

Succinate of Tin is a crystalline Salt in tables, produced by dissolving the oxide in the Acid and slow evaporation.

By the aid of heat, oxalic Acid first blackens Tin, and then incrusts its surface with a white oxide, of which a portion is taken up. Prismatic crystals may be obtained by slow evaporation.

Tartrate of Tin is formed by dissolving the metallic oxide in tartaric Acid. By boiling oxide of Tin in a solution of tartrate of potash, a very soluble, but crystallizable, double Salt is formed, from which the alkalis and their carbonates produce no precipitate. (*m.*)

Deutoxide of Tin appears also to dissolve in nitrate of ammonia, producing a double Salt in solution. (*l.*)

(670.) L. The effects of reagents upon solutions of Tin are as follows. Gallic Acid and infusion of galls, no precipitate. Prussiate of potash, a white one. Hydrosulphuret of potash, a dark brown one in Salts of the protoxide, and a deep yellow precipitate in those of the deutoxide. Corrosive sublimate produces in the former Salts black, in the latter white precipitates. Lead precipitates Tin from some of its Salts in the metallic state. With the protosalts a solution of gold produces a purple precipitate.

(671.) M. Tin is of importance in the Arts for the formation of several alloys. The bronze of the Ancients, a very beautiful compound, sufficiently hard for the formation of swords and spear-heads, consisted of 88 parts of copper and 12 of Tin. Gun-metal is of about the same composition. (*n.*) (*o.*) In bell-metal the Tin is from one-fifth to one-third of the weight of the copper. The Chinese gong is formed of 80 of copper and 20 of Tin. (*p.*) For the specula of telescopes, Mudge recommends 1 part of Tin to 2 of copper; but Mr. Edwards's experiments are in favour of a more complex material, consisting of 32 of copper, 15 or 16 of Tin, with brass, arsenic, and silver, each 1 part. (*q.*) The surface of copper-vessels for culinary purposes is often covered with a film of Tin, to prevent the poisonous effects produced by solution of the former Metal. The process is extremely simple: the copper being first polished, and then covered with a coating of sal ammoniac or pitch, to prevent oxidation, and the vessel being heated, the Tin is applied hot, and readily adheres to the surface of the copper. On similar principles the manufacture of Tin-plate is effected; thin sheets of polished iron are dipped into a vat of melted Tin, having a coat of tallow floating upon its surface. The Tin unites with the surfaces of the iron forming with it an alloy to a slight depth. Pewter is of very variable composition, but most is formed from Tin and lead; the best, however, contains only Tin with a little antimony. This compound may safely be used even for vinegar; for unless the lead be in improper excess, none of it is taken up by the Acid; but if any solution takes place, it is only of a small quantity of Tin. Nitric Acid, on the contrary, takes up more of the lead than of Tin. Plumbers' solder contains equal parts of Tin and lead. In silvering mirrors, Tin-foil is spread on flat stones, and then covered with quicksilver; the glass is then so applied as to remove as much as possible of the mercury, and the remaining amalgam adheres to the surface of the glass. The oxides of Tin are the principal basis of white enamel; and some of its Salts are of great use as mordants in dyeing. (*r.*)

References to § 3.

(*a.*) *Hist. Nat.* ch. xvii. lib. xxxiv. (*b.*) No. xxxi. p. 22. (*c.*) *Geo. Trans.* vol. i. (*d.*) Pajot, *Jour. de Phys.* vol. xxxviii. (*e.*) Gay Lussac, *An. de Ch.* vol. lxxx. (*f.*) Nich. *Jour.* vol. xxxv. (*g.*) *Phil. Trans.* 1812. (*h.*) *Opusc.* vol. iii. p. 471. (*i.*) *Opusc.* vol. ii. (*k.*) *Jour. de Phys.* vol. li. (*l.*) Thenard, *An. de Ch.* vol. xlii. (*m.*) Thenard, *An. de Ch.* vol. xxxviii. (*n.*) Pearson, *Phil. Trans.* 1796. (*o.*) Dizé, *Jour. de Phys.* 1790. (*p.*) Thomson, *An. Phil.* vol. ii. (*q.*) Mudge, Nich. *Jour.* vol. iii. and Little, Nich. *Jour.* vol. xvi. (*r.*) Mode of Making Tin Plate, Watson, *Essays*, vol. ix. and Parkes, *Manch. Mem.* N. S. vol. iii.; Proust, Nich. *Jour.* vol. xiv.; Pelletier, *Mém. de Ch.* tom. i. and ii.

Sect. IV.—*Zinc.*

(672.) A. Metallic Zinc was unknown to the Ancients, though they were well acquainted with its ore, and used it largely in the formation of brass. Owing to its volatile nature and strong affinity for oxygen they never obtained it in the reduced form, though its oxide formed some of their medicinal preparations. Pliny says, *Plura autem genera sunt, namque ipse lapis ex quo fit æs, cadmia vocatur.* (*a.*) Henckel first mentions its reduction in 1721. Zinc has never been found in the metallic state, but exists abundantly as a sulphuret and carbonate: sometimes also combined with oxygen and silica.

(673.) B. The reduction of Zinc is performed on a large scale in Britain, principally from the sulphuret; the ore is roasted, and then reduced to powder, mixed with charcoal, and violently heated in earthen melting-pots. It either passes in fusion through an iron tube from the bottom of these crucibles, or is volatilized; and in both cases, the tube terminating in a vessel of water, the Metal is condensed, and subsequently fused into convenient masses for market. (*b.*)

To obtain pure Zinc for Chemical purposes, let the Metal be dissolved in sulphuric Acid to saturation, leaving a plate of the Metal a short time in the solution, by which all impurity of foreign Metals will be precipitated. Decompose the filtered solution by an alkaline carbonate, and reduce the powder produced; by mixing it with half its weight of charcoal, and submitting it to a strong heat in a retort, the pure Zinc will condense in the beak of the vessel, which is to be kept cool.

(674.) C. Zinc is of a bluish-white colour, of a laminated structure, and fine granular fracture, Specific Gravity 6.8 to 7.1, more malleable than antimony, but less so than copper or lead; rather ductile, but at ordinary temperatures not very elastic. At a temperature from 212° to 310° it becomes very malleable, and may be formed into thin sheets by passing it between steel rollers; at 400° it becomes again quite brittle, and may be pulverized, and at about 480° Fahrenheit it fuses. (Black.) By higher temperatures it is capable of distillation in close vessels.

(675.) D. Though the surface of Zinc becomes tarnished, it can scarcely be said to undergo oxidation by exposure to the air. At ordinary temperatures it very slowly decomposes water; but if watery vapour be passed over Zinc made red hot, a most rapid decomposition is effected, the Metal becomes oxidated, and hydrogen is evolved. If Zinc be fused in an open vessel, it forms a greyish oxide. But if an earthen crucible be heated red hot, and small pieces of Zinc be projected into it, a most intense white light marks rapid combustion, and an abundance of white flakes are carried up by the current of heated air. This delicate white powder, the *nihil album, lana philosophica* of the Alchemists, Flowers of Zinc of the early medical writers, is the pure white oxide of this Metal. This substance is not volatile, and very difficult of fusion; insoluble in water, it absorbs carbonic Acid from the atmosphere, is not decomposed by heat, but reducible by the Voltaic pile; and by heat, if in contact with charcoal, the Metal distils over in closed vessels. It is the only oxide which Chemists have been able to procure from this Metal.

(676.) E. Zinc readily takes fire in chlorine Gas, and a chloride of Zinc is formed. By evaporating a solution of hydrochlorate of Zinc to dryness, and subsequent exposure to a red heat in a glass tube with a minute orifice, the same substance is produced. In this state, according to Dr. John Davy, (*c.*) it is not capable of being sublimed by a low red heat.

(677.) F. Zinc is soluble in fluoric Acid, and it seems very probable that by exposure to heat the Salt so formed would be converted into a fluoride of Zinc.

(678.) G. If iodine and Zinc be fused together, iodide of Zinc is formed. It is a volatile compound, which on condensation crystallizes in small quadrangular prisms, which deliquesce by exposure to air, and are soluble in water. In this state it becomes, in fact, a solution of hydriodate of Zinc.

(679.) H. Zinc unites with phosphorus, forming a metallic-looking compound. The sulphuret of this Metal cannot be directly formed by melting the two substances together, but if, instead of metallic Zinc, its oxide is fused with sulphur, a true sulphuret is formed. The same substance is precipitated by dropping an alkaline hydrosulphuret into a solution of Zinc. According to Mr. E. Davy, if the vapour of sulphur is passed over Zinc in fusion, a yellowish compound, similar to blende, is produced. The properties of Zinc and selenion are precisely similar to those just described. Direct union is impossible, but when volatilized selenion comes in contact with fused Zinc red-hot, an instantaneous combination takes places with such violence, as to produce a sort of detonation. (*d.*) Zinc has not been united to boron or silicon, and it is stated not to combine with hydrogen or azote. It must, however, be remembered that most Chemists are of opinion, that in the common process of obtaining hydrogen by the action of sulphuric Acid and Zinc upon water, some portion of the Metal is carried up along with the Gas.

(680.) I. Zinc has been alloyed with potassium, sodium, (*e.*) iron, antimony, copper, gold, silver, lead, tin, and mercury. It is said that it refuses to unite with nickel and cobalt.

(681.) K. Nitric Acid readily dissolves Zinc or its oxide; and in operating upon the Metal it is advisable to moderate the action, by using the Acid in a dilute state. By evaporation, this nitrate is said to crystallize in "flat, striated, tetrahedral prisms, terminated by four-sided pyramids." These crystals are soluble in water and alcohol. They are entirely decomposed by a sufficient heat.

Concentrated sulphuric Acid has little action upon Zinc without heat, but if diluted, dissolves it with rapidity. By evaporation, the sulphate of Zinc crystallizes in four-sided, rectangular prisms, terminated by tetrahedral pyramids. In this state it is the *white vitriol* of Commerce. By a strong and continued heat, it is entirely decomposed, leaving oxide of Zinc in great purity.

Sulphurous Acid dissolves oxide of Zinc, forming a crystallizable sulphite which is not soluble in alcohol.

On metallic Zinc, sulphurous Acid exerts a considerable violence of action, and hydrosulphuric Acid Gas is given out, the water undergoes an entire, and the Acid a partial, decomposition; oxygen goes to the Zinc, and part of the sulphur escapes in combination with the hydrogen; thus the Acid becomes the hyposulphurous, and being neutralized by the oxide, hyposulphite of Zinc remains. By spontaneous evaporation, slender, four-sided crystals, with pyramidal summits, are produced. These are soluble in water and alcohol. (Fourcroy.)

The carbonate of Zinc occurs native, and is known by the name *calamine;* it exists both as an hydrous and as an anhydrous Salt. A solution of carbonic Acid dissolves both Zinc and its oxide, but the carbonate is more readily formed by adding an alkaline carbonate to a solution of Zinc. The Salt precipitates in the form of a white powder; but is again dissolved by excess of the precipitating Acid.

Borate of soda in solution, added to sulphate of Zinc in the same state, throws down a white powder, consisting of borate of Zinc, which heat fuses, but does not decompose.

Phosphoric Acid dissolves Zinc, but ceases to act when the Salt has arrived at the state of a biphosphate, which may be evaporated just to dryness without crystallization or decomposition. If, however, such a saturated solution be boiled upon carbonate of Zinc, a true insoluble phosphate of Zinc is formed.

Berzelius has described the seleniate and biseleniate of Zinc; (*f.*) the former is insoluble, the latter soluble in water.

The arseniate, antimoniate, tungstate, molybdate, and chromate of Zinc, are formed by adding their alkaline Salts to a solution of sulphate of Zinc; in all cases a white, insoluble powder is precipitated, the chromate excepted, which is of an orange-red colour.

Acetic Acid dissolves Zinc; and by evaporation a crystalline acetate is obtained, readily soluble in water.

The benzoic, succinic, malic, and lactic Acids, dissolve Zinc, and form crystallizable Salts, which are again soluble in water.

The oxalic, citric, and tartaric Acids also attack Zinc, but the Salts which are thus formed, immediately separate from being insoluble in water.

A double tartrate of potash and Zinc may be formed by boiling tartaric Acid and Zinc filings in water. (*g.*) A double sulphate of Zinc and iron is formed by mixing a solution of sulphate of iron with that of sulphate of Zinc; the Salt is soluble, and may be obtained in crystals by evaporation. Sulphate of Zinc and cobalt may be formed by digesting zaffre in a solution of sulphate of Zinc. It crystallizes in large, four-sided prisms. (*h.*)

A mineral substance, known by the name of electric calamine, consists of silica and oxide of Zinc; and here the former substance is considered to perform the part of an Acid; it is therefore called silicate of Zinc. The crystalline forms are numerous; a small hexagonal prism or an acute octahedron is the most common.

Caustic ammonia is capable of dissolving the oxide of Zinc, and has even some action on the Metal; after which a mass of plumose crystals may be obtained by evaporation. From such a solution copper precipitates Zinc; but Zinc precipitates copper from an Acid. May not this tend to prove that the oxide of Zinc here acts the part of an Acid?

(682.) L. Many of the instances in which saline solutions form reagents for the separation of Zinc, may be collected from the preceding section. Its Salts, when in solution, are always colourless. Alkalis produce a white precipitate, soluble in sulphuric or hydrochloric Acid. Prussiate of potash, hydriodate of potash, hydrosulphate of potash, and hydrosulphuric Acid Gas, produce white precipitates. Gallic Acid and infusion of galls give no precipitate. Zinc is not thrown down in the metallic state from its solution by any other Metal.

(683.) M. The sulphate of Zinc is used as an emetic, and the acetate has recently been recommended by Dr. Henry as an external application to remove inflammation. It has long formed a constituent of some empiric eye-waters.

Zinc is principally obtained on the large scale for the formation of brass. This useful and beautiful alloy commonly consists of about 62 to 66 of copper, with from 32 to 35 of Zinc; (Chaudet;) the more valuable kind, known by the name of Dutch brass, was found by Thomson to contain 70 of copper and 30 of Zinc, but he considers that much of its superiority consists in the greater purity of the Metals, which in common brass are contaminated with lead. (*i.*) When the copper is in greater proportion, other Metals are formed, known in Commerce by the names of pinchbeck, Prince's metal, &c. A considerable quantity of Zinc is employed for the plates of galvanic batteries. Its white oxide forms a pure and delicate white paint. Recently it has been much employed for making the shoots carried round the eaves of houses to collect rain-water.

References to § 4.

(*a.*) *Hist. Nat.* ch. xxxiv. sec. 10. (*b.*) Watson, *Essays*, vol. iv. (*c.*) *Phil. Trans.* 1812. (*d.*) Berzelius, *An. de Ch. et Ph.* vol. x. (*e.*) Gay Lussac and Thenard, *Recherches.* (*f.*) *An. de Ch. et Ph.* vol. ix. (*g.*) Thenard, *An. de Ch.* vol. xxxviii. (*h.*) Link, Crell's *Annals*, 1796. (*i.*) *An. Phil.* vol. xii.

Sect. V.—*Cadmium.*

(684.) A. In the year 1817, Professor Stromeyer of Gottingen discovered the oxide of a peculiar Metal as an impurity in oxide of zinc, sold for medicinal purposes; while at the same time a peculiarity in a preparation of zinc, from the manufactory of M. Hermann in Silesia, led to the observation of the same metallic oxide. The oxide of zinc had been condemned on the supposition that it contained arsenic, because it produced an orange precipitate with hydrosulphuric Acid Gas. On more accurate investigation, this suspicion was found to be without foundation; and some of the orange precipitate having been transmitted to Stromeyer, he recognised in it the same metallic oxide, to the Metal from which he gave the name of Cadmium. (*a.*) This Metal has since been found in some of the English ores of zinc by Professor Clarke of Cambridge; (*b.*) but its most abundant ore is the brown fibrous blende of Bohemia. Mr. Herapath has pointed out an abundance of the oxide also in the sublimate from zinc furnaces. (*c.*)

(685.) B. Stromeyer's process for obtaining the Metal is as follows. A solution of the ore or oxide is made in sulphuric Acid, by passing a current of hydrosulphuric Acid Gas through the Liquid; the Cadmium, zinc, and copper, if present, are precipitated. Redissolve in concentrated hydrochloric Acid, and evaporate to dryness, to get rid of the excess of Acid. Dissolve in water, and add excess of carbonate of ammonia, by which the zinc and copper are dissolved, but the carbonate of Cadmium remains in the state of a fine white powder. At a red heat the Acid is driven off, and oxide of Cadmium remains. This oxide may be reduced to the metallic state by mixing it with lamp-black, and exposure to a low red heat in a glass tube or small retort.

The following elegant process for obtaining Cadmium is from Dr. Wollaston. From the solution of the ore, precipitate all other metallic impurities by a plate of iron; filter, and immerse a plate of zinc in the clear solution: if Cadmium be present, it will be precipitated in the metallic state, and may be redissolved in hydrochloric Acid, for the exhibition of appropriate tests.

(686.) C. Cadmium is of a bluish-white colour, and, much like tin, susceptible of a fine polish. Its texture is compact, and Specific Gravity 8.604—8.694. It fuses, and is volatilized below a red heat; in fact, at a heat rather above that of boiling mercury. It crystallizes in octohedrals, is flexible, and gives, on bending, the same sound as tin does. It is ductile and malleable, yielding readily to the knife; but exceeds tin in hardness and tenacity.

(687.) D. When Cadmium is heated with access of air, it burns, and the smoke condenses in the form of a brown powder, its only known oxide. In this state it is readily soluble in nitric Acid, and feebly so in dilute hydrochloric, sulphuric, and acetic Acids. Oxide of Cadmium is soluble in ammonia, but not in the fixed alkalis.

(688.) E. If oxide of Cadmium be dissolved in hydrochloric Acid, small rectangular crystals of hydrochlorate of Cadmium are obtained by evaporation. By heat these are converted into chloride of Cadmium, and are even capable of volatilization unaltered.

(689.) F. Unknown.

(690.) G Iodine and Cadmium, if heated together, readily unite. Or if water be boiled upon the two substances in contact, a solution is obtained, which by evaporation may be crystallized in the form of hexagonal plates. These crystals are decomposed by heat, and are soluble in water and alcohol.

(691.) H. The combinations which ought to fall under this head are at present little investigated. Cadmium and sulphur do not unite readily by fusion, but the sulphuret is easily formed by passing a current of hydrosulphuric Acid Gas through a solution of a Salt of Cadmium. The yellow sulphuret thus produced, forms, according to Stromeyer, an excellent paint. By the action of nitric Acid, the sulphuret is converted into a neutral sulphate. The phosphuret of Cadmium is a grey, metallic-looking, brittle substance, easily fusible; placed on burning coals it ignites, and is converted into the phosphate.

(692.) I. As yet Cadmium has been alloyed only with copper, mercury, cobalt, platinum, and zinc.

(693.) K. The Salts of Cadmium are at present little known. The nitrate, sulphate, and acetate are soluble in water. The carbonate, phosphate, and oxalate are insoluble in water. The borate, tartrate, and citrate are very slightly soluble.

(694.) L. In solutions of Cadmium the fixed alkalis produce permanent precipitates, but ammonia produces a precipitate which excess of the alkali again dissolves. "The alkaline carbonates throw down Cadmium in the state of a white carbonate. This carbonate does not form an hydrate, as is the case with carbonate of zinc. Neither is it redissolved by adding excess of carbonate of ammonia, as is the case with carbonate of zinc, unless there previously existed a notable excess of Acid in the solution."

"Phosphate of soda throws down Cadmium in the state of a white powder, zinc in the state of crystalline scales." Thomson.

Hydrosulphuric Acid Gas and the hydrosulphurets produce a yellow precipitate, easily soluble in hydrochloric Acid, and unaltered by a low red heat; in which two points it differs from orpiment.

Prussiate of potassa precipitates solution of Cadmium white.

Infusion of galls gives no precipitate.

Cadmium is precipitated by zinc in the metallic state.

(695.) M. None at present.

References to § 5.

(*a.*) Stromeyer, *An. Phil.* vol. xiii.; Gilbert, *Annalen*, vol. lx.; *An. Phil.* vol. xiv. p. 269. (*b.*) Clarke, *An. Phil.* vol. xv. p. 272. (*c.*) Herapath, *An. Phil.* N. S. vol. iii. p. 435.

METALS. CLASS IV

Sect. I.—*Arsenic.*

(696.) A. "The word Arsenic (*ἀρσενικὸν*) occurs first in the Works of Dioscorides, and some authors who wrote about the beginning of the Christian era. It denotes in their Works the same substance which Aristotle had called *σανδαράχη*; and his disciple Theophrastus *ἀρρενικὸν*, which is a reddish-coloured mineral, composed of Arsenic and sulphur, used by the Ancients in painting, and as a medicine. (*a.*)

"The white oxide of Arsenic, or what is known in Commerce by the name of Arsenic, is mentioned by Avicenna, in the XIth century; but at what period the Metal called Arsenic was first extracted from that oxide is unknown. Paracelsus seems to have known it; and a process for obtaining it is described by Schroeder in his Pharmacopœia, published in 1649. But it was only in the year 1733, that this Metal was examined with Chemical precision. This examination, which was performed by Mr. Brandt, (*b.*) demonstrated its peculiar nature; and since that time it has been always considered as a distinct Metal, to which the term *Arsenic* has been appropriated. Its properties were still further investigated by Macquer, in 1746, (*c.*) by Monnet, in 1773, (*d.*) by Bergman, in 1777. (*e.*) To the labours of these Philosophers, and those of Mr. Scheele, (*f.*) we are indebted for almost every thing known about the properties of this Metal. Its combinations with oxygen have been carefully examined by Proust, (*g.*) Bucholz, (*h.*) Berzelius, (*i.*) and some other Chemists." (*k.*) Thomson. (*l.*)

Arsenic exists native, in the state of an oxide; and as a constituent part of many metalliferous ores.

(697.) B. To obtain metallic Arsenic, let the white oxide of Commerce be mixed with half its weight of black flux; (made by deflagrating two parts of crystals of tartar with one part of nitre in a crucible.) Put the mixture into a crucible; invert over this another crucible, and let the two be luted together with sand and clay. Expose the lower crucible to a red heat, and let the upper one be kept as cool as possible. Brilliant metallic Arsenic will be found sublimed into the upper crucible. A wide earthen tube-retort, divided into two parts, would be more convenient.

(698.) C. Arsenic is so brittle and soft that it may easily be pulverized. It is readily fusible, and rises in vapour at about 356° Fahrenheit. When thrown on a red-hot iron, it burns with a blue flame and a white smoke, having a strong alliaceous odour. This odour is not present when only the oxides of Arsenic are volatilized.

(699.) D. If Arsenic be moderately heated with free access of atmospheric air, sublimation takes place, and a white powder is condensed, which is Arsenious Acid. See subsect 1.

Besides this oxide another exists having also acid properties. This was discovered by Scheele; and the process recommended by Bucholz for obtaining it is as follows. Mix two parts of hydrochloric Acid, Specific Gravity 1.2; eight parts of Arsenious Acid; and twenty-four parts of nitric Acid. (Specific Gravity 1.25.) Evaporate the mixture to dryness, giving at last a low red heat. (*m.*) The same Acid is still more readil obtained by dissolving Arsenic in nitric Acid, and evaporating to dryness. See subsect 2.

As far as at present known, the following is the composition of these two oxides:

	Arsenic.		Oxygen.
Arsenious Acid......	one atom	+	two atoms.
Arsenic Acid........	one atom	+	three atoms.

In this and all such cases it is surely more easy to speak of the deutoxide and tritoxide of Arsenic, and to remember that the protoxide has not yet been exhibited, than it is to speak of the protoxide, and to remember that it contains an atom more oxygen than protoxides in general; and of the deutoxide, having also to remember that it is similarly circumstanced.

(700.) E. Arsenic undergoes combustion in chlorine Gas, and a true chloride of Arsenic is formed. It is most fully described by Dr. Davy. (*n.*)

(701.) F. Unknown.

(702.) G. Iodine and Arsenic unite to form a deep red iodide, which is capable of decomposing water and affords Arsenic and hydriodic Acids.

(703.) H. Arsenic unites with hydrogen to form a gaseous substance; (*o.*) but there is considerable danger in making experiments upon it, as the mere inhaling a small quantity killed M. Gehlen. (*p.*)

Arsenic unites with sulphur in two proportions, and both compounds are found native: these are realger and orpiment. (*q.*) It combines also with phosphorus and selenion.

(704.) I. This Metal combines to form alloys with all the other Metals; and has even in very small quantity the property of rendering them quite brittle.

(705.) K. The oxides of Arsenic seem to possess little power of performing the parts of a base in the formation of Salts. The sulphate, borate, phosphate, nitrate, and hydrochlorate of Arsenic, have been described. In these Salts, the Acid and base are held by very feeble affinities.

But the oxides of Arsenic are capable of more important effects in performing the part of Acids with certain bases; and hence has been called Arsenious and Arsenic Acids.

(706.) L. In Medical Jurisprudence, a decisive test of Arsenic is a matter of great importance; as upon it the life of an accused person must frequently depend. Several tests have been proposed for this purpose, but, as it would seem, all are more or less uncertain. For an able investigation of this point we are indebted to Dr. Christison; and from his Memoirs we give the following summary of what he considers a faultless process for the purpose. Let the mass of fluids suspected of containing Arsenic, suppose for instance the contents of the stomach of a deceased person, be well agitated and boiled with water, and thrown on a filter. Be careful to acidulate the clear Liquid with hydrochloric or acetic Acid. Through this Liquid pass a current of hydrosulphuric Acid Gas, (sulphuretted hydrogen.) Suppose a yellow precipitate to be formed. It may be the sulphurets of Arsenic, cadmium, tin, antimony, or selenion. But the sulphuret of Arsenic will easily be recognised by the following properties. Let a portion of it be dried; mixed with a little *black flux*, (697.) placed in a dry glass-tube, and raised to a red heat in the flame of a spirit-lamp. The Arsenic is reduced, rises in vapour, and is condensed in the form of a bright iron-grey crust lining the cooler part of the tube. The inner surface presents also a crystalline appearance. By vaporizing a little of this Metal, the alliaceous odour of garlic is instantly perceptible. This evidence is quite conclusive. But it is easy also to reconvert the Metal into Arsenious Acid. For this purpose hold the part of the tube to which the Arsenic adheres about three-fourths of an inch above the flame of a very small spirit-lamp, so that the Metal may rise in vapour very gradually. In so doing it combines with oxygen, and is deposited in well-characterized crystals of Arsenious Acid, on the cooler parts of the tube. It is essential that the tube be quite dry. The volatility, form, transparency, and adamantine lustre are so characteristic, that Dr. Christison considers that one-hundreth of a grain is sufficient to satisfy an experienced eye. This gentleman states that he has been able by these processes to separate and exhibit in two instances so small a quantity as the twentieth of a grain from the stomachs of people who had been poisoned with Arsenic. (*r.*)

(707.) M. Arsenic, in the form of its yellow sulphuret, forms a pigment, being the colouring principle of *King's yellow.* The sulphurets of Arsenic are poisonous, but not to such an extent as the Metal or its oxides. Preparations of Arsenic have been employed in Medicine, and form the active ingredient in Fowler's Ague-drops.

Subsect. 1.—*Arsenious Acid.*

(708.) Having previously stated the formation and constitution of Arsenious Acid, (699.) we may here note a few of its principal properties, though in so doing we must be as brief as possible. According to Klaproth and Bucholz, cold water dissolves only .25 per cent. of its own weight of white Arsenic; whilst boiling water takes up 7.775 per cent. A part was again deposited on cooling, but 4.775 per cent. remained in solution. This oxide is soluble also in alcohol and oils. Arsenious Acid is capable of neutralizing the alkaline bases: and thus forms a class of Salts called Arsenites. It unites in a similar manner with several metallic oxides.

Subsect. 2.—*Arsenic Acid.*

(709.) The formation of this Acid has been noticed in Art. 699. It reddens vegetable blues; attracts moisture from the atmosphere; effervesces strongly with solutions of alkaline carbonates. By evaporation it gelatinizes, but does not crystallize. It unites also with bases, forming a class of Salts called Arseniates.

References to § 1.

(*a.*) *Hist. Nat.* lib. xxxiv. ch. xviii.; and consult Salmasius in Solin. p. 1154. (*b.*) *Mem. Phil. Soc. Upsala*, 1733, p. 39. (*c.*) *Mem. Par.* 1746, p. 223; and 1748, p. 35. (*d.*) *Sur l'Arsenic.* (*e.*) *Opusc.* vol. ii. p. 272. (*f.*) *Essays*, vol. i. p. 129. (*g.*) *Jour. de Phys.* 1799, p. 151. (*h.*) *Jour. de Chim.* vol. iv. p. 5. (*i.*) *An. de Ch.* vol. lxxx. p. 9. (*k.*) *An. Philos.* vol. iv. p. 171. (*l.*) *Syst.* vol. i. p. 305. (*m.*) Van Mons, *Jour. de Ch.* vol. iv. p. 16. (*n.*) *Phil. Trans.* 1812, p. 186. (*o.*) *Jour. Roy. Inst.* vol. xiii. p. 225. (*p.*) *An. de Ch.* vol. xcv. p. 110; and *An. de Ch. et de Ph.* vol. iii. p. 135; Stromeyer, Nich. *Jour.* vol. xix. p. 381. (*q*) Laugier, *An. de Ch. et de Ph.* vol. v. p. 179; Berzelius, *An. Phil.* vol. xv. p. 359; Braconnot, *An. de Ch. et de Ph.* vol. xii. p. 98. (*r.*) *Edin. Med. and Surg. Journal*, October, 1824; and *Transactions of the Medico-Chirurgical Society*, vol. ii.

Sect. II.—*Molybdenum.*

(710.) A. This, which is now the name of a peculiar Metal, was used by Pliny (lib. xxv. ch. xiii.) for *plumbago, genus herbæ, &c. &c. quod plumbum, id est oculorum vitium, commanducata tollit;* also, in lib. xxxiv. ch. xviii. it is explained as *vena communis plumbi et argenti.*

In 1778, Scheele analyzed this substance and obtained sulphur, and a white powder possessed of Acid properties, to which he gave the name of "Acid of Molybdena." Hjelm, in 1782, succeeded in reducing it to the metallic state; his process depended upon subjecting the oxide to intense heat after it had been mixed up with linseed-oil, but according to Bucholz, the addition of carbonaceous matter is unnecessary.

(711.) B. This Metal has hitherto resisted all efforts to reduce it to a metallic button, as the most successful experimentalists have but produced a porous mass of adhering particles.

(712.) C. Its colour is silvery-white, and the highest Specific Gravity to which Bucholz could bring it was 8.61. It appears as if under all states it would prove brittle.

(713.) D. If Molybdenum be heated in an open vessel, it undergoes oxidation, producing small, bright, needle-formed crystals, and, according to Bucholz, it is capable of forming three oxides. Mr. Hatchett is disposed to admit four.

The protoxide is said to be formed by dissolving Molybdic Acid in ammonia, and evaporating the clear solution to dryness; the residuum is exposed to a white heat with charcoal in a crucible. A brown oxide is formed at the bottom of the crucible, having a crystalline appearance, but incapable of forming Salts with Acids.

The deutoxide, or *Molybdous Acid*, (subsect. 1.) is to be formed, by mixing one part of Molybdenum with two parts of Molybdic Acid in a state of powder; the mass is to be mixed with hot water, and triturated till it becomes blue: eight or ten parts of water are added, and boiled for a few minutes. The solution is then filtered and evaporated at a temperature of 120°. The blue oxide remains in the state of a fine powder, soluble in water, which is strongly acid, converting vegetable blues to red, and saturating bases so as to form Salts.

The white oxide, or Molybdic Acid, is prepared from Molybdena, (the native sulphuret of the Metal,) by the following process of Bucholz. Expose the mineral, finely pulverized, to heat, in an open crucible, stirring it with an iron rod till the whole is of an ash-grey colour. The sulphur is driven off, and by a moderate but continued heat the Molybdenum is oxidated. It is then pulverized, and digested in a solution of ammonia in water, by which the Molybdic Acid is taken up. After this solution has remained in a close vessel to deposit its sediment, it is decanted off, and, by dropping in nitric Acid, the Molybdic Acid is precipitated in a fine white powder. See subsect. 2.

(714.) E. F. G. The first of these combinations has been formed, and it is not improbable that the others may be so hereafter.

(715.) H. Molybdenum unites with phosphorus and sulphur.

(716.) I. It may be combined also with all the Metals, those only excepted the volatility of which does not allow of their being exposed to a sufficient degree of heat.

(717.) K. Both the Molybdous and Molybdic Acids are capable of neutralizing bases and forming Salts; but Salts, in which an oxide of Molybdenum serves as a base, have not been recognised: in fact, as these two higher oxides are precipitated by Acids, no such combination with them is to be expected.

(718.) L. An excellent Synoptic Table of the effect of reagents on solutions of Molybdenum is given by Professor Thomson, (*a.*) which we regret we have not space to insert. Perhaps the most marked test is that a drop of muriatic Acid, and a piece of metallic tin, being placed in such a solution, produce a blue colour, and a blue, pulverulent precipitate.

(719.) M. None.

Subsect. 1.—*Molybdous Acid.*

(720.) For this, not very important, compound we must refer to Bucholz's Memoir. (*b.*)

Subsect. 2.—*Molybdic Acid.*

(721.) In a close vessel it fuses and crystallizes, but in an open one it is sublimed, and when again condensed has the form of glittering, yellow scales. It is soluble in 960 parts of boiling water, and the solution reddens litmus. The mineral Acids reproduce the white precipitate. By heat, the Molybdic Acid is soluble in sulphuric Acid, giving a colourless solution, which, however, becomes blue when cold; and this colour is increased by saturating the Acid with soda. It is also soluble in muriatic Acid, but not in the nitric. If to a muriatic solution metallic tin be added, a blue colour is produced by altering the degree of oxidation. With the nitrates of silver, mercury, and lead, white precipitates are formed; with nitrate of copper a greenish one. With neutral solutions of sulphate of zinc, muriate of bismuth, muriate of antimony, nitrate of nickel, and the muriates of gold and platinum, it gives white precipitates, according to Vauquelin. If paper be dipped in this Acid, and exposed to the light of the Sun, it assumes a beautiful blue colour.

References to § 2.

(*a.*) Thomson's *First Principles*, vol. ii. p. 58.
(*b.*) Bucholz, Gehlen's *Journal*, vol. iv.; consult also Scheele, *Essays*, vol. i.; Bergman, *Opusc.* vol. iii. p. 128; Pelletier, *Jour. de Ph.* 1785; Hjelm, Crell's *Annals*, 1787; Hatchett, *Phil. Trans.* 1795; Hjelm, Gehlen's *Jour.* vol. iv.; Berzelius, *An. Phil.* vol. iii.; Pelletier, *An. de Ch.* vol. xiii.; Vauquelin, *Phil. Mag.* vol. i.

Sect. III.—*Chromium.*

(722.) A. This Metal derived its name from the varied and beautiful colour of its Salts. (χρῶμα, colour.) The Siberian ore, in which it is combined with lead, was first described by Lehman, in 1766; and, after several inaccurate examinations, Vauquelin and Klaproth, about the same time, pronounced it to be a new Metal. Its principal ores are the beautiful Siberian red chromate of lead, from Beresof, and a dark, opake chromate of iron. It is also considered as the colouring principle of both the ruby and the emerald.

(723.) B. The Metal is obtained by submitting the oxide, mixed with charcoal, to an intense heat. According to Richter, the charcoal from sugar answers best.

(724.) C. Chromium is white, very brittle, capable of a high polish, and, according to Richter, slightly magnetic. Specific Gravity 5.9. Fusible only at very high temperatures.

(725.) D. Chromium is not altered by exposure to the air, but if heated, it is gradually converted into a green oxide. At the three degrees of oxidation with which we are acquainted, it is green, brown, and yellow, or red; in the last state it becomes an Acid.

The green oxide may also be obtained by submitting Chromic Acid to heat, by which it is partly decomposed. When this oxide is precipitated from its solution in Acids, it is of a deep green colour, and contains water, which may be driven off by heat. In its first state it is soluble in Acids, but if subjected to a heat rather below redness, it becomes of a lighter green, and insoluble; yet without losing any of its weight.

The brown oxide may be obtained by dissolving the green oxide in nitric Acid, then evaporate and heat the dry mass until it ceases to give out nitrous fumes. A brown powder remains, which is scarcely soluble in alkalis, and not at all in Acids. If heated with hydrochloric Acid, chlorine is evolved, and the green oxide is produced; which proves that the brown powder was the Metal in a higher degree of oxidation. Chromium, in its third degree of oxidation, forms Chromic Acid, which will be found in subsect. 1.

(726.) E. If metallic Chromium be dissolved in nitro-muriatic Acid, a hydrochlorate of Chromium results; and by desiccation this is converted into a true chloride of Chromium.

(727.) F. G. It is pretty well established that both these elements form Gaseous combinations with Chromium.

(728.) H. In this department few experiments have been made; but Chromium is known to unite with sulphur and phosphorus.

(729.) I. With some of the Metals Chromium has been combined, but with some it seems unwilling to unite.

(730.) K. Chromium is not soluble in the mineral Acids, the nitro-muriatic excepted. In these Acids the green oxide is soluble with difficulty. It is soluble also in the alkalis.

(731.) L. Solutions of Chromium produce a green precipitate with prussiate of Potash; a brown one with infusion of galls; and a green one with hydrosulphurate of potassa.

(732.) M. Perhaps the most beautiful fixed pigments with which we are acquainted, arise from the oxides of this Metal. In miniature-painting, the chromate of lead is highly esteemed: the oxide gives a bright green to porcelain, and imparts the same hue to the glass or paste by which the emerald is imitated. M. Lassaigne has shown that Chromium might be applied with advantage to dyeing and calico-printing. (*a.*) A red subchromate of lead, formed by Dulong, (*b.*) has been proposed by Mr. Badams as a die for cotton. (*c.*)

Subsect. 1.—*Chromic Acid.*

(733.) Chromic Acid is obtained by the decomposition of either the chromate of lead or of iron. If the former, let it be reduced to a fine powder, and boiled in a fixed alkaline solution, which thus becomes an orange-coloured solution of the alkaline chromate. Add sulphuric Acid and evaporate. The crystals of Chromic Acid may then be separated from the alkaline sulphates. As the chromate of iron is more abundant of the two, it is generally employed for obtaining the Acid, for which the following process is employed. Let the ore be reduced to a fine powder, and mingled with an equal weight of nitre. The whole is to be submitted to a red heat for half an hour in a crucible. A yellow frit is produced, from which all the soluble part is to be removed by long boiling in water. The clear Liquid containing the chromate of potash is neutralized by nitric Acid, and then by addition of nitrate of mercury a red precipitate of chromate of mercury is produced. This precipitate is to be well washed, dried, and decomposed by heat in a retort: the mercury is driven off, and the Chromic Acid remains pure.

The Salts formed by Chromic Acid with alkaline, earthy, and metallic bases are highly interesting. All so formed from white oxides are yellow when neutral, or in the state of subsalts, and are reddish yellow when acid. Chromate of lead is yellow; of protoxide of mercury, red; of silver, purple. The chromates of the first and last four classes of Metals are decomposed at high temperatures, leaving oxide of chromium and the base. By great heat, with aid of charcoal, a perfect reduction may be obtained.

The chromates of potassa, soda, ammonia, glycyna, yttria, lime, magnesia, protoxide of nickel and of cobalt, are soluble.

The insoluble chromates with their colours are barytes and strontia, white or yellow; of silver, crimson; of mercury, red; of lead, orange or yellow; of copper, apple green; of iron, brown; of uranium, zinc, and bismuth, yellow; of antimony, brown.

With solutions of nickel, zinc, tin, cobalt, gold, or platinum, no precipitate is produced.

References to § 3.

(*a.*) Lassaigne, *An. de Ch. et de Ph.* vol. xiv. p. 299; vol. xv. p. 76; vol. xvi. p. 400. (*b.*) *An. de Ch.* vol. lxxxii. p. 292. (*c.*) *An. Phil.* N. S. vol. ix. p. 303; consult also Vauquelin, *An. de Ch.* vol. xxv. p. 21, and p. 149, vol. xxvi.; Klaproth, Crell's *An.* 1798; also *An. de Ch.* vol. xxxii. xxxiii. xxxiv.; Moussin Pouschkin, Crell's *An.* 1798; Gmelin, Crell's *An.* 1799; Richter, Gehlen's *Jour.* vol. v.; Goden, *An. de Ch.* vol. liii.; Vauquelin, *An. de Ch.* vol. lxx.; Berzelius, *An. Phil.* vol. iii.; John, *Chemisch. Laborat.* vol. iv., or *An. Phil.* vol. iv.; Thomson, *Phil. Trans.* 1827; Unverdorben, *Edin. Jour. Sci.* No. 7.; Grouvelle, *An. de Ch. et de Ph.* vol. xvii.; Thomson, *An. Phil.* vol. xvi.

Sect. IV.—*Tungsten.*

(734.) A. Scheelium, or Wolframium, the Swedish mineral Tungsten, (heavy stone,) was analyzed by Scheele in 1781, who obtained lime and a white pulverulent substance, which he considered a peculiar Acid, and which Bergman supposed to be a metallic oxide. The D'Elhuyarts obtained it also from the mineral *Wolfram*, and succeeded in reducing it to the metallic state.

(735.) B. The best method for procuring the Metal is that of Allen and Aikin, subjecting tungstate of ammonia to an intense heat. The oxide is reducible by charcoal.

(736.) C. The Metal, from its extreme infusibility, has only been seen in a mass consisting of small agglutinated grains of a greyish-white colour, and some brilliancy. It is so hard as scarcely to be affected by the file. Its Specific Gravity, according to Bucholz, 17.4. It seems to assume a crystalline form on cooling, and not to be affected by the magnet.

(737.) D. Tungsten, if heated in an open vessel, will absorb oxygen, with which it may be made to combine in two proportions in forming brown and yellow oxides. Berzelius obtained the brown oxide, by passing a current of hydrogen over the yellow oxide in a glass tube heated to redness. Water was formed, and a brown oxide remained, which when heated in the open air burns like tinder, and becomes Tungstic Acid. See subsect. 1.

(738.) E. F. G. Unexamined.

(739.) H. The sulphuret has been formed and examined by Berzelius.

(740.) I. The D'Elhuyarts formed alloys of Tungsten by subjecting a mixture of Tungstic Acid, charcoal, and any Metal, to a strong heat. In this manner it was combined with gold, silver, copper, iron, lead, tin, antimony, bismuth, and manganese. The principal obstacle to be overcome appeared to arise from the great infusibility of the Metal itself.

(741.) K. Tungstic Acid, as will be seen hereafter, forms Salts by uniting with bases; but Salts, in which any oxide of Tungsten performs the part of a base, have not been recognised.

(742.) L. An ore of Tungsten is recognised by calcining it with its own weight of nitre; a portion of the frit is soluble in water, forming a colourless solution. Nitric Acid throws down a white precipitate, which, by being well washed in boiling water, becomes yellow, and has the properties of Tungstic Acid.

(743.) M. None.

Subsect. 1.—*Tungstic Acid.*

(744.) The Tungstic Acid of Scheele was in fact a triple Salt, but the true yellow oxide, which appears to possess acid properties, may be thus obtained. Let three parts of Hydrochloric Acid be boiled on one part of Wolfram. The clear Liquid is to be decanted off and left at rest. A yellow powder gradually separates, which is to be redissolved in ammonia; the clear solution, evaporated to dryness, leaves the yellow oxide in a state of purity. It is insoluble in water, and though it does not exert any action upon vegetable colours, it is capable of saturating bases. Good analyses have given such approximations to the theoretical numbers of the Table, that no others need here be given.

Tungstate of lime is found native. The tungstates of ammonia, potash, soda, and magnesia are soluble, those of lime, barytes, strontia, manganese, and iron are not so.

References to § 4.

Consult Scheele, *Ess.* vol. ii. p. 81; D'Elhuyarts, *Mém. Acad. Thoulouse*, vol. ii.; Vauquelin and Hecht, *Jour. de Mines*, No. 19.; Klaproth on the Minerals of Cornwall; Aikin's *Dict.*; Berzelius, *An. Phil.* vol. iii.; Bucholz, *An. Phil.* vol. vi.; Bucholz, *Jour. de Ch.* vol. iii.; Berzelius, *Afhandlingar*, vol. iv.; Pelletier, *An. de Ch.* vol. xiii.

Sect. V.—*Columbium.*

(745.) A. In the year 1801 Mr. Hatchett obtained from the analysis of a mineral in the British Museum, similar in appearance to chromate of iron, a new metallic oxide, possessed of acid properties. It had been sent from America, and, therefore, to the inferred metallic base of the oxide, he gave the name of Columbium. Ekeberg soon after discovered in a Swedish mineral a metallic oxide which he considered new, and called Tantalum, from the name of the mineral itself. Dr. Wollaston having examined the substance, found it identical with the Columbium of Hatchett. Columbium occurs in the mineral from Massachusetts, and in the tantalite and yttro-tantalite of Sweden.

(746.) B. Dr. Wollaston's method for obtaining this oxide from the mineral tantalite is as follows. Mix one part of tantalite with five of carbonate of potash and two of borax, and fuse in a platinum crucible. Soften the mass with water, and digest it in hydrochloric Acid. The iron and manganese are dissolved, and a white powder remains, which is the oxide of Columbium. By subjecting this oxide, mixed with charcoal, to an intense heat, Berzelius reduced it, although unable to produce a bead of fused Metal.

(747.) C. Columbium has a dark-grey colour, is capable of metallic lustre, hard enough to scratch glass, and may be reduced to a dark-brown powder. Its Specific Gravity can scarcely be said to be accurately known.

(748.) D. When heated, Columbium takes fire, and burns feebly to an imperfect-grey oxide. It detonates slightly with nitre in a red-hot crucible. The white mass produced by the deflagration is a mixture of oxide of Columbium and potash. The potash may be separated by hydrochloric Acid, leaving behind a hydrous, white oxide, which has the singularity of being soluble in oxalic, tartaric, and citric Acids. After the water has been driven off by heat, this property disappears, and the pure oxide is insoluble in nitric and sulphuric Acids, but imperfectly so in the muriatic. It is capable of reddening vegetable blues, and with potash as a base it forms a crystallizable Salt. This is *Columbic Acid*, subsect. 1.

(749) E. F. G. H. I. Little known, save that it has been alloyed with some other Metals.

(750.) K. Columbium resists the action of hydrochloric, nitric, and nitro-muriatic Acids.

(751.) L. Columbium must be tested in the state of columbic Acid, or a columbate. See, therefore, subsect. 1.

(752.) M. None.

Subsect. 1.—*Columbic Acid.*

(753.) On this point we may briefly state that Columbic Acid is scarcely at all soluble in water. Insoluble in Acids, save the fluoric. Soluble in acid tartrate of potassa; also in potassa and soda. For the full action of this substance with tests, we must dire[illegible] the reader to Dr. Thomson's *First Principles*. (*a*.)

References to § 5.

(*a*.) vol. ii. p. 77; consult also Hatchett, *Phil. Tra*[illegible] 1802, p. 49; Ekeberg, *Vetensk. Ac. Handl. Stoc*[illegible] 1802; Wollaston, *Phil. Trans.* 1809; Berzeli[illegible] *Afhandl.* vol. iv.; *Id. An. Phil.* vol. iv.; Wollast[illegible] Nich. *Jour.* vol. xxv.; Berzelius, *An. de Ch. et de* [illegible] vol. xxix. p. 303.

Sect. VI.—*Antimony.*

(754.) A. The Ancients obtained with their silver ores an oxide of this Metal, to which the name στίμμι, or *stibium*, was applied. Pliny thus speaks of it. *In iisdem argenti metallis invenitur, ut propriè dicamus, spumæ lapis candidæ nitentisq; non tamen translucentis, stimmi appellant, alii stibium, alii alabastrum, alii larbason.*" Lib. xxxiii. ch. vi. He enumerates its medicinal virtues, and particularizes its application to the eyes. Thus employed as an ornamental pigment, its use is of high antiquity; at least that such a custom prevailed we learn from *Ezekiel*, ch. xxiii. v. 40., and among the Eastern ladies it is continued to this day. They colour the eyelids black with a substance of which the Arabic name is *Kohol*, this being some preparation of Antimony. Dr. Thomson has shown, by a singular quotation from Thallinus, that its use was continued in Spain during the Middle Ages, under the name of "*piedra de alcohol*." The Alchemists were well acquainted with the substance, and doubtless received from Arabia or Egypt the name *kohol*, with the article *al* prefixed; hence their usual term *alcohol*, though many other names were given to it from its properties. In 1624, the *Currus Triumphalis Antimonii* of Basil Valentine, a Monk of Erfurt, appeared. As the title implies, the virtues of this mineral form the subject of the Work. It is not improbable that through him, or some one in his time, the word Antimony came into use. Legends tell that the Monkish experimentalist, who practised as a Physician, made trial of its virtues upon the hogs of the Convent. The medicine acted as a brisk cathartic, and the pigs speedily fattened. Encouraged by this happy result, he administered it to some of his brother Monks; but the dose being too violent it proved fatal, and hence the name ἀντὶ μοναχοὺς, or "Anti-moine."

It is found but sparingly in the state of an oxide, but very abundantly as a sulphuret, which ore is the *crude Antimony* of Commerce; also in native crystals of considerable purity.

(755.) B. Antimony may be obtained from its sulphuret for the purposes of the laboratory by mixing three parts of the ore with two of tartar and one of nitre; this powder is to be gradually projected into a hot crucible, which is then exposed for three-quarters of an hour to a furnace or forge-heat. On cooling, the button of Antimony is found at the bottom of the crucible. By this process the Metal is not obtained in a state of great purity; for delicate purposes it must be revived from the oxide. Thenard suggests the passing a current of hydrogen over the oxide in a heated porcelain tube, as the most unobjectionable method.

(756.) C. In colour, Antimony is greyish-white, with considerable brilliancy. Its texture is laminated and imperfectly crystalline. According to Haüy, (*a*.) the primary form is an octohedron. By friction it communicates to the fingers a peculiar taste and smell. Its hardness nearly equals gold. Its Specific Gravity, according to Hatchett, is 6.71. It is so brittle as to be easily pulverized. According to Muschenbroeck, a wire one-tenth in diameter supports a weight of about ten pounds. It fuses at about 810° of Fahrenheit, and is volatilized by greatly increased heat; but from the experiments of Thenard it would appear that the Metal is fixed if air be excluded, and that the volatilization which takes place is that of the oxide.

(757.) D. There is considerable difference of opinion as to the number of oxides which Antimony is capable of forming, but of three at least there is good evidence. By exposure to air or water, the Metal undergoes no alteration, but at a red heat it decomposes steam with such rapidity as to produce a violent explosion.

1. The protoxide is a white or grey powder, easily fusible. It may be obtained by dissolving the Metal in hydrochloric Acid, and diluting the solution largely with water; a white precipitate is obtained; which, after being well washed, is to be boiled in a solution of carbonate of potassa, to remove an adhering portion of hydrochloric Acid. This powder, when again washed and dried, is the protoxide.

2. The hemideutoxide (deutoxide of some) is a fine white powder, not so fusible as the former, nor so easily soluble in Acids, and insoluble in water; it is obtained by heating the protoxide in an open vessel nearly to redness. It takes fire, absorbs oxygen, and is converted into the oxide. It is produced also by the action of hot nitric Acid upon Antimony. By heating the Metal in a furnace with free access of air, a white oxide is sublimed, (argentine flowers of Antimony,) which Thomson considers to be this, while Thenard asserts that it is the former oxide.

This oxide possesses acid properties, and combines with bases producing the *Antimonites*. It has been called Antimonious Acid. See subsect. 1.

3. The remaining known oxide, the deutoxide, (peroxide of some,) is also an Acid, and called the Antimonic. See subsect. 2. It may be formed by mixing six parts of nitre and one of Antimony in a silver crucible, and exposing it to a low red heat for an hour. The excess of alkali is to be washed off with a little cold water. Digest the remaining powder in hot water, which will dissolve a part. From this solution, acetic Acid precipitates a hydrate of antimonic Acid. The water may be driven off by a gentle heat, and the powder thus obtained is incapable of combining with Acids, but reddens vegetable blues; and is, in fact, completely an Acid, as it unites with bases to form Salts. By a red-heat it is converted into the preceding oxide.

Of the constitution of these oxides no very decided account can be given, the reader is therefore referred to the Table for the nearest theoretical assumption.

The antimoniate of potash is formed in the above process, and many metallic antimoniates exist, but have not yet been made the subject of investigation.

(758.) E. The action of chlorine upon this Metal produces the following beautiful experiment. Into a stopped glass jar containing chlorine, pour, by means of a funnel, some finely powdered Antimony, which has been previously warmed. The rapid combination produces a beautiful shower of fire within the jar.

(759.) F. Unexamined.

(760.) G. Iodine combines with Antimony, but by water is again separated into hydriodic Acid, and the white oxide.

(761.) H. With carbon, boron, silicon, azote, and hydrogen, we know of no compound, but with phosphorus, sulphur, and selenion, it readily unites.

(762.) I. With the Metals it readily unites, and generally to the destruction of their ductility.

(763.) K. Boiling sulphuric Acid undergoes a violent action upon Antimony; it is decomposed, giving out sulphurous Acid Gas; an imperfect sulphate is produced, which, however, is decomposed by a plentiful effusion of water, and the white oxide of the Metal subsides to the bottom.

The sulphurous Acid has no action upon Antimony, but it decomposes many of its Salts. From the hydrochlorate, a white precipitate is produced, which, according to Aikin, is a true sulphate of Antimony.

Upon this Metal, nitric Acid, even when cold, undergoes rapid decomposition; nitrous Gas is evolved, and a white oxide is produced. If the Antimony be reduced to fine powder, and mingled with just Acid enough to form a paste, the action is so violent as to cause inflammation. Another singular consequence of the partial decomposition of the water, together with that of the Acid, is that the liberated hydrogen of the former unites with the azote of the latter, and ammonia is produced. The addition of a small quantity of fixed alkali or caustic lime will disengage the Ammonia, which may be recognised by its pungency, or by the fumes of hydrochloric Acid.

The hydrochloric Acid dissolves Antimony, but in very small quantity; on the oxide its action is much greater; a thick, honey-like substance is the result, which formerly went by the name of *Butter of Antimony*, and is a highly corrosive substance.

Strong nitromuriatic Acid dissolves this Metal in considerable quantity, but the whole is again precipitated in the state of an oxide by water.

From all these instances we may fairly conclude that Antimony, when oxidated in the higher degrees, can no longer as a base unite with Acids to form Salts; but it may assist in the formation of Salts with certain bases, to which it performs the part of an Acid.

The only true Salts of Antimony then contain the protoxide; of the mineral Acids there probably are few if any, as their own decomposition furnishes oxygen for the formation of the insoluble white oxide. From the vegetable Acids, the acetate, succinate, benzoate, oxalate, and tartrate have been described. One triple Salt, however, claims peculiar notice, as the *Tartar Emetic* of Medical writers. It consists of tartaric Acid, potash, and protoxide of Antimony. Alkalis, alkaline earths, sulphurets, several metals, and astringent vegetable decoctions, decompose it. With any of these, therefore, it ought never to be conjoined in a prescription.

The solutions of the Salts of this Metal are generally yellow, and precipitable by water. Prussiate of potassa and tincture of galls give a white precipitate, but only from their water determining the deposition of the white oxide. From hydrosulphurets, a yellow precipitate is produced. A plate of iron or zinc throws down the Metal in the state of a black powder, especially if the solution be acidulated.

(764.) L. In the Arts an alloy of this Metal with lead is used for the plates upon which music is engraved; and with tin it forms one kind of pewter. It enters also with lead and copper into the composition of printers' types. Its oxide assists in the vitrification of earths, and gives to glass an amethystine hue. Combined with oxide of lead, it forms a paint called *Naples yellow*, and enters into some enamels. Of its application to medicinal purposes the tartrate has been noticed. The *Glass of Antimony* of the old Pharmacopœia is a fused sulphuret. The *Kermes Mineral* is an hydrosulphuretted oxide. The celebrated Fever-powder of Dr. James appears, from the analysis of Dr. Pearson, (*b.*) to be a combination of phosphate of lime with oxide of Antimony, which is imitated in the *Pulv. Antimonialis* of the Materia Medica.

Subsect. 1.—*Antimonious Acid.*

(765.) If Antimony be burned or strongly heated in an open vessel, an oxide is formed, the constitution of which is at once expressed by our term of the hemideutoxide; it is condensed upon any cold surface in the form of shining, white, acicular crystals. This substance was formerly called *Argentine flowers of Antimony.* It unites with alkalis to form a class of Salts.

Subsect. 2.—*Antimonic Acid.*

(766.) Dr. Thomson obtained this Acid by dissolving pure metallic antimony with nitric Acid in a platinum crucible. The solution was evaporated to dryness, and exposed for some hours to a heat of 500° Fahrenheit. This acid oxide is a yellow powder, and is converted by a red heat into the oxide preceding. The same able Chemist has suggested, and with great probability, that the hemideutoxide is a compound of one atom of the protoxide + one atom of the deutoxide. Berzelius formed and described the Antimoniate of potassa.

References to § 6.

(*a.*) *Jour. de Mines, An.* 5. (*b.*) *Phil. Trans.* 1791; consult also Basil Valentine, *Currus Triumphalis Antimonii;* Meuderi *Analysis Antimonii Physico-Chemicus rationalis*, 1788; Lavoisier and Meusnier, *Mém. Par. Acad.* 1781; Thenard, *An. de Ch.* vol. xxxii.; Proust, *Jour. de Phys.* vol. lv.; Berzelius, Nich. *Jour.* vol. xxiv. xxv.; *An. Phil.* vol. iii.; Thomson, *An. Phil.* vol. iv.; J. Davy, *Phil. Trans.* 1812; Bergman, *Opusc.* vol. iii.; Thomson, *First Principles*, vol. ii. p. 40.

Sect. VII.—*Uranium.*

(767.) A. On examining a Saxon mineral called *Pechblende*, Klaproth, in 1789, discovered that it was the sulphuret of a new Metal. Herschel had just discovered his new Planet, and as the German Astronomers gave to it the name of Uranus, the Chemist gave to his new Metal the name of Uranium. The beautiful green uranite of Cornwall is an hydrated oxide of this Metal.

(768.) B. To obtain the Metal from pechblende by digestion in nitric Acid, the Uranium, iron, copper, and lime are taken up. Evaporate to dryness, and redissolve in water, which will leave the peroxide of iron. By digestion in ammonia the Uranium is precipitated, and the copper retained in solution. The precipitate is to be again dissolved in nitric Acid, evaporated and crystallized. The green crystals are picked out, slightly washed, dissolved in water, and, by a second crystallization, they are supposed to be obtained free from the lime. By exposure to a red heat a yellow, pulverulent oxide remains. This oxide, mixed with one-twentieth of charcoal powder, and exposed to intense heat, is reduced. In this, and probably in many other cases, too much charcoal should not be employed.

(769.) C. Thus obtained, Uranium is not a very compact button, as a much greater heat is required for its perfect fusion than our furnaces can produce. Its physical properties are little known; it yields to the file; and, according to Professor Clarke, of Cambridge, a pure bead, produced by acting upon the nitric green oxide with the Gas blowpipe, was brittle.

(770.) D. At a red heat, in an open vessel, Uranium is converted into a greyish-black powder, which, by continued heat, is unaltered, and is the protoxide. The yellow powder, above described, is the deutoxide, which is also obtained by precipitation from the nitrate by an alkali.

It would appear from recent experiments, especially those of Dr. Thomson (*a.*) and Arfwedson, (*b.*) that the higher oxide of Uranium is, in fact, possessed of acid properties, and can neutralize bases. The constitution of the oxides of Uranium is by no means well settled; for, supposing the dark-green oxide to be a protoxide, it remains doubtful whether the yellow oxide is a hemideutoxide, or a deutoxide: Thomson is of the latter opinion.

(771.) E. F. G. Little studied, or unknown.

(772.) H. Bucholz succeeded in forming an artificial sulphuret of Uranium.

(773.) I. Nitric Acid readily dissolves Uranium, or its oxide; and by evaporation, a crystallized nitrate, of a lemon-yellow colour, is obtained. It is deliquescent, very soluble in water, and moderately so in ether, but shortly undergoes decomposition. A subnitrate, insoluble in water, is described by Bucholz. Sulphuric Acid has very little action on Uranium. But it dissolves, with some difficulty, the oxide, if assisted by heat, and a crystallized sulphate may be obtained. Berzelius describes a seleniate and biseleniate. The phosphate, arseniate, tungstate, molybdate, and tartrate may be found by precipitation from a Salt of Uranium with Salts of these Acids. Richter obtained also the borate, oxalate, citrate, mallate, benzoate, and succinate. Acetic Acid dissolves the oxide, and forms a crystallizable salt soluble in water.

Besides these Salts, in which oxides of Uranium constitute the base, it is quite well established that the yellow oxide of Uranium performs the part of an Acid also to certain bases. See subsect. 1.

(774.) K. For the reagent effects of Uranium, consult a valuable series of facts given in Thomson's *First Principles*, vol. ii. Generally speaking, the caustic alkalis give yellow precipitates with Salts of Uranium not soluble in excess of alkali; with their carbonates a white one, which is soluble in excess. Prussiate of pótassa a dark, red-brown precipitate.

(775.) L. With proper fluxes the oxide of Uranium gives an orange colour to porcelain.

Subsect. 1.—*Uranic Acid.*

(776.) To preserve the uniformity of our plan we introduce this name. Uraniate of barytes is described by Berzelius. This Acid seems to have a great tendency to take part in the formation of double Salts.

References to § 7.

(*a*.) *First Principles*, vol. ii. p. 2. (*b*.) *An. Phil.* N. S. vol. vii. See also Klaproth, Crell's *Annals*, vol. i.; Bucholz, Gehlen's *Jour.* vol. iv.; Klaproth, *Analyt. Essays*, Eng. Trans. vol. iv.

Sect. VIII.—*Cerium.*

(777.) A. In the year 1750, a mineral, having considerable resemblance to tungsten, was found in the copper-mine of Bastnâs in Sweden. Bergman published an attempt at its analysis by MM. D'Elhuyart, by which it was proved not to be tungsten. Klaproth afterwards declared it to contain a new earth, which he called *Ochroita*. Hissinger and Berzelius made a more complete examination of the substance, and, considering it a metallic oxide, they gave to the Metal the name of Cerium, from the coincidence of the discovery of the Planet Ceres about the same time. It has subsequently engaged the attention of Vauquelin, Thomson, and Laugier. Three minerals contain this substance, two from Sweden, and one from Greenland.

(778.) B. Cerium is best obtained by the process of Laugier. The mineral Cerite is dissolved in nitro-muriatic Acid; a precipitate is produced by ammonia, which is well washed, and, while still moist, is treated with a solution of oxalic Acid, which dissolves out the oxide of iron which had been thrown down; the remaining powder is, after calcination at a red heat, pure oxide of Cerium. Several attempts have been made to reduce this oxide to the metallic state, but with partial success; for though a metallic powder has been produced, it has never been formed into a mass, so that its physical properties are almost unknown. Sir H. Davy effected the decomposition of the oxide of Cerium by the action of potassium.

(779.) C. M. Vauquelin obtained some small grains of metallic Cerium, which were brittle and of a white colour. According to Messrs. Children and Thomson, Cerium may be volatilized by a very intense heat.

(780.) D. If Cerium be dissolved in nitro-muriatic Acid; the solution neutralized with caustic potassa; then precipitated by tartrate of potassa; and lastly, after washing, be calcined, oxide of Cerium is obtained. This is Cerium in its highest degree of oxygenation. The two oxides of this Metal would seem to be a protoxide and a hemideutoxide.

(781.) E. F. G. Unknown.

(782.) H. Laugier obtained a carburet of Cerium; and there is reason to suppose that a phosphuret may be formed. Also a sulphuret by indirect processes.

(783.) I. According to Gahn, Cerium would not unite with lead; but Vauquelin succeeded in forming an alloy with iron.

(784.) K. According to Vauquelin, the reduced metallic powder is insoluble in all unmixed Acids, and not easily so in even the nitro-muriatic. The oxides are soluble in most Acids. The Salts of the protoxide at present known are the protonitrate, protosulphate, protocarbonate, protoseleniate, and protoxalate. Those of the red oxide are, the nitrate, sulphate, seleniate, and oxalate. There also exist combinations of oxide of Cerium with the phosphoric, arsenic, molybdic, acetic, benzoic, succinic, tartaric, and citric Acids; but of the state of oxidation of the Metal in these cases we are not well assured; for the most part they seem to contain the protoxide. A double Salt of sulphuric Acid with potassa and oxide of Cerium, is described by the Swedish Chemists.

(785.) L. Of the protoxide, the Salts are colourless, or white; and of the peroxide they are yellow. Their solutions in water have a sweet taste. Gallic Acid and hydrosulphuric Acid Gas give no precipitate. Hydrosulphuret of potash and prussiate of potassa give a white precipitate. Oxalate of ammonia produces a white precipitate soluble in nitric and hydrochloric Acids. Tartrate of potash gives no precipitate, but arseniate of potash gives a white precipitate. "Succinate of ammonia does not precipitate Cerium from the acetate, which furnishes a ready means of separating iron from Cerium."

(786.) M. None known.

References to § 8.

(*a*.) Bergman, *Opusc.* vol. vi.; Klaproth, Gehl. *Jour.* vol. ii., or Nich. *Jour.* vol. viii.; Hissinger and Berzelius, Nich. *Jour.* vol. ix.; Gahn, Gehl. *Jour.* vol. iii.; Vauquelin, *An. de Ch.* vol. l. and vol. liv.; Thomson, *Phil. Trans. Edin.* vol. vi.; Laugier, *An. de Ch.* vol. lxxxix.; Hissinger, *An. Phil.* vol. iv.

Sect. IX.—*Cobalt.*

(787.) A. Cobalt was recognised as a distinct metallic substance by Brandt in 1733, but had long been used to give a blue colour to glass. According to Lehman, Christopher Schurer, a glass-maker at Platten, was the first to use it thus in about 1540. Cobalt is found in several states of mineral combination, and is almost constantly attended by arsenic.

(788.) B. For commercial purposes, the Cobalt ore is roasted; by which volatile and fusible substances are removed, and some silica within an impure oxide remains, which is called zaffre. Many processes have been recommended for obtaining pure Cobalt; one of the best is as follows. Reduce zaffre to the metallic state, by mixing it with thrice its weight of black flux, a little oil, and a little salt; expose this mixture to a strong heat in a crucible for some hours, and a button of Cobalt will be found at the bottom of the crucible. In this state it is usually alloyed with iron, copper, nickel, and arsenic. Pulverize the metallic button, and calcine with four parts of nitre; after which hot water will remove the arseniate of potassa. Dissolve the residuum in dilute nitric Acid, and precipitate the copper by a plate of iron. By filtering, evaporation to dryness, and digestion in hydrate of ammonia, the oxides of nickel and Cobalt will alone be taken up. Expel the excess of ammonia by heat, and add dilute hydrate of potassa, which will precipitate the nickel. By immediately filtering and boiling the clear liquor the oxide of Cobalt is precipitated, and may be reduced by subjecting it to a strong heat with charcoal and a little oil.

(789.) C. Thus obtained, Cobalt is of a reddish-grey colour, of a fibrous or laminated texture. Brittle, but said to be malleable when heated. Its Specific Gravity has been stated at from 7.7 to 8.7. It is not volatile; and, after fusion, may, by care, be obtained in a crystalline form. Like iron and nickel, it possesses permanent Magnetic properties.

(790.) D. Cobalt at a red heat in an open vessel undergoes oxidation. The protoxide is however best obtained by dissolving the Metal in nitric Acid, and precipitating by hydrate of potassa: the precipitate is at first blue, but becomes black, and is the higher oxide of this Metal. By exposing this oxide to a low red heat, one portion of oxygen is driven off, and protoxide, which has a beautiful blue colour, is produced.

(791.) E. The chloride may be formed by gently heating filings of the Metal in chlorine; it is also formed by evaporation of the hydrochlorate, and is a very definite compound.

(792.) F. G. The iodide and fluoride are unknown.

(793.) H. The phosphuret, sulphuret, and seleniuret, have been examined, but of any combination with carbon, boron, silicon, hydrogen, or nitrogen, we are ignorant.

(794.) I. Cobalt has been alloyed with gold, platinum, tin, copper, iron, antimony, arsenic, and lead; but it would scarcely, if at all, unite with silver, mercury, bismuth, or zinc.

(795.) K. As we have before seen, Cobalt is soluble in nitric Acid when heated, and red prismatic crystals may be obtained.

The muriatic Acid attacks this Metal but with great difficulty, and the solution was formerly known by the name of Hellot's Sympathetic Ink; a better Salt for this purpose will, however, be described hereafter. The oxide is readily soluble.

At a boiling heat, sulphuric Acid is decomposed upon Cobalt, and a soluble sulphate remains, but the oxide is not very soluble in this Acid. Carbonate, borate, seleniate, arseniate, antimoniate, antimonite, oxalate, and tartrate of Cobalt, may be formed by precipitation where the Salts are neutral. Oxalic Acid attacks and dissolves metallic Cobalt, but phosphoric, fluoric, tartaric, and acetic Acids, only dissolve the oxide. The *Acetate of Cobalt* forms an excellent sympathetic ink, by which if any thing be written or painted upon paper, it is invisible when cold, but becomes of a fine azure blue when exposed to heat. The most probable cause that has been assigned for this change is, that, when suffered to cool, the muriate or acetate of Cobalt, being very deliquescent, absorbs moisture, and undergoes a sufficient dilution to be colourless; but that by heating they become concentrated, and the green or blue colour is developed. This view of the matter is confirmed by the fact, that the same colour is produced by exposing the washed paper to the absorbent action of quick-lime, or sulphuric Acid in an exhausted receiver.

Neutral solutions of the Salts of Cobalt are generally of a reddish colour.

(796.) L. In neutral solutions of Cobalt the alkalis produce a blue precipitate, prussiate of potassa a light-green one. Hydrosulphuric Acid Gas no precipitate; but hydrosulphuret of potash a black one, soluble in excess of the precipitate. Gallic Acid produces no change, but tincture of galls gives a white precipitate. Metallic zinc produces no precipitate, neither does its hydriodate, nor that of potassa.

(797.) M. Cobalt is employed in the Arts to give a blue colour to glass, enamel, and porcelain. *Zaffre* has been already described, but as it is found in Commerce it is always mixed with two parts of powdered flint.

Small is a finely pulverized glass, coloured by oxide of Cobalt. Aikin states that so high is the colouring power of this metallic oxide, that one grain will give a full blue colour to 240 grains of glass.

References to § 9.

Brandt, *Acta. Upsal.* 1733 and 1742; Lehman, *Cadmialogia;* Bergman, *Opusc.* vol. ii.; Tassaert, *An. de Ch.* vol. xxviii.; Fourcroy, *Jour. de Mines, Disc. Prélim.;* Thenard, *An. de Ch.* vol. xlii.; Proust, *An. de Ch.* vol. lx.; Richter, Gehlen's *Jour.* vol. ii.; Bucholz, Gehlen's *Jour.* vol. iii.; Phillips, *Phil. Mag.* vol. xvi.; Rothoff, *An. Phil.* vol. iii.; Thenard, *Jour. de Mines,* vol. xii. p. 215.

Sect. X.—*Titanium.*

(798.) A. In the year 1791, the Rev. Mr. Gregor published the analysis of a black sand found in the parish of Menachan in Cornwall. Finding that it contained the oxide of a new Metal, it received the name of Menachine from Kirwan. Little interest was excited till, four years afterwards, Klaproth discovered that what was called red schorl consisted of the same oxide nearly in a state of purity. To the Metal he gave the name Titanium, which is generally adopted. It has since been found in anatase, iserine, and sphene, and frequently forms those beautiful brown filaments which traverse rock crystal.

(799.) B. The native red oxide is not soluble in Acids, but may be decomposed by fusion with two parts of potash, or six parts of its carbonate. The fused mass is to be digested in diluted hydrochloric Acid, which is to be decanted off when it has removed all the soluble part. To this hydrochloric solution, oxalate of ammonia is to be added; by which, oxalate of Titanium is precipitated, while the iron remains in solution. By calcination, the vegetable Acid is destroyed, and a yellow oxide remains, which becomes white on cooling. The reduction of this oxide has proved of the utmost difficulty, and has been frequently attempted without success. By forming the oxide into a paste with oil, and exposing it to a most intense heat, Laugier appears to have effected it.

(800.) C. The colour of the Metal produced was that of gold; it was brittle, but in a slight degree elastic, having considerable lustre, but highly infusible; according to Vauquelin it may be volatilized by an intense heat.

(801.) D. When heated with access of air, it changes its colour and undergoes oxidation, forming a blue powder, which is said to be the first oxide. The native red schorl is the second, and the last is the white powder already described.

This powder has feeble acid properties; hence it has been called Titanic Acid. (Subsect. 1.)

(802.) E. Metallic Titanium unites with chlorine; and it would appear that two chlorides of Titanium exist. (*a.*)

(803.) F. G. Unknown.

(804.) H. Sulphur was united with Titanium by Rose, and with phosphorus by Chenevix.

(805.) I. Vauquelin and Hecht were unable to alloy Titanium with silver, copper, lead, or arsenic; but they did combine it with iron. Dr. Wollaston obtained similar results.

(806.) K. Though nitric Acid has little action on either the Metal or the red oxide, it will, if aided by heat, dissolve the carbonate, and a crystallized nitrate may be obtained, provided that the Metal be in its first degree of oxidation. The Metal is soluble (though the red oxide is not) in hydrochloric Acid, and a Salt forming cubic crystals is produced; but according to Vauquelin a gelatinous mass is produced by evaporation, which by increased heat is decomposed, chlorine is liberated, and an oxide precipitates, which is insoluble in hydrochloric Acid, but yields to the nitric. Hence it is inferred that the hydrochlorate contains the white oxide and that no combination can exist between this Acid and the protoxide. Boiling sulphuric Acid oxidates and dissolves the Metal, but affects not the red oxide; it acts readily on the carbonate, but this metallic sulphate has not as yet been seen in a crystalline form. The phosphoric and arsenic Acids, if added to the solutions of this Metal, produce insoluble white precipitates. The carbonate is formed by fusing together six parts of carbonate of potassa and one part of the red oxide; the mass is to be well washed with water, and the insoluble white powder remaining is the Salt. Oxalic and tartaric Acids produce also white precipitates, but these are again redissolved by any excess of Acid.

The Salts are colourless, and have different degrees of solubility.

(807.) L. Alkaline carbonates produce a white flaky precipitate, prussiate of potash a grass-green inclining to brown; "but if an alkali is added after the prussiate, the precipitate becomes purple, then blue, and at last white." Hydrosulphuret of potash produces a dirty-green precipitate; sulphuretted hydrogen produces none at all; infusion of galls a bulky reddish-brown precipitate. A rod of tin immersed in a clear solution of Titanium becomes gradually surrounded by a fine red cloud, and a rod of zinc by a blue one.

(808.) M. In the Arts, Titanium has been sparingly employed to produce a brown or yellow colour on porcelain.

Subsect. 1.—*Titanic Acid.*

(809.) The existence of this Acid is doubtful, for Rose has stated that he could not detect true acid properties in the oxide of Titanium; we leave it, however, for future examination.

References to § 10.

(*a.*) Gregor. *An. Phil.* N. S. vol. ix. p. 18. (*b.*) Rose, *An. Phil.* N. S. vol. vi. p. 369; Gregor. *Jour. de Ph.* vol. xxxix; Klaproth, *Beitr.* vol. i. p. 233, and vol. ii. p. 226; Vauquelin and Hecht, *Jour. de Mines*, No. 15; Crell, *Annals*, 1799, vol. i. p. 183; Chenevix, Nich. *Jour.* vol. v. p. 134; Lampadius, Nich. *Jour.* vol. vi. p. 62; Laugier, *An. de Ch.* vol. lxxxix.

Sect. XI.—*Bismuth.*

(810.) A. Bismuth was unknown to the Ancients, but appears to have been early recognised by the German miners. According to their speculations it was an imperfect silver, but by the successive researches of Chemists it was first deemed an alloy, and at length recognised as a peculiar Metal. It is found native, but contaminated with arsenic, as an oxide, and as a sulphuret.

(811.) B. Being easily fusible, it is separated from its ores by subjecting them to the heat of a furnace in iron tubes, inclined so that the Metal may run out at one end.

(812.) C. In colour, Bismuth is reddish-white, and has a laminary structure. In hardness it is inferior to copper. According to Hatchett its Specific Gravity is 9.822. It is not malleable, nor of great tenacity. Its fusing point is 451° according to Berzelius, but Gay Lussac makes it as high as 541. If a mass of Bismuth, fused in a crucible or ladle, be suffered partly to congeal, and the fluid portion be poured off from the other, a very beautiful crystallization is seen in rectangular parallelopipeds. The primary form, according to Haüy, is an octahedron. (*Jour. de Mines, An.* 5.) It has long been said that, by increased heat, Bismuth may be sublimed; this, however, is denied by Thenard.

(813.) D. The action of air or water is not alone sufficient to produce oxidation, but by continuing the Metal in a state of fusion with free access of air, a film of oxide forms upon the surface. At a strong red heat it takes fire, emitting a yellow smoke, which when condensed is no longer volatile, and forms the yellow oxide of Bismuth. It is tasteless, and insoluble in water, but fusible.

(814.) E. If Bismuth, finely powdered, be introduced into chlorine it takes fire, and the metallic chloride is produced.

(815.) F. Unknown.

(816.) G. Iodine, by the aid of heat, enters into combination with Bismuth, and this iodide, though insoluble in water, may be dissolved in caustic potassa without precipitation.

(817.) H. Bismuth combines readily with sulphur and selenion, scarcely, if at all, with phosphorus, and not with hydrogen or carbon.

(818.) I. All Metals seem capable of uniting with this to form alloys, and in general a great increase of fusibility is the result. Newton's fusible Metal is a striking example, consisting of eight parts of Bismuth, five of tin, and three of lead. It melts at a heat considerably below that of boiling water, and the addition of one part of mercury adds still more to its fusibility.

(819.) K. The action of nitric Acid upon Bismuth is very violent, much nitrous Gas is evolved, and the Metal undergoes oxidation. With slightly dilute Acid a soluble nitrate is produced, which on cooling is precipitated in small crystals.

Cold sulphuric Acid exerts no action upon Bismuth, but by the assistance of heat, the Metal is converted into a white powder, and sulphurous Acid is evolved. By washing with a small quantity of water, a portion of the metallic sulphate is carried off, and may be obtained by evaporation.

Arsenic Acid digested upon this Metal with a moderate heat, converts it into a white powder, which is arseniate of Bismuth.

Hydrochloric Acid, if heated, acts upon Bismuth, and very readily on its oxide, and a crystallizable hydrochlorate is produced, which is, like the nitrate, precipitable by water; by the action of heat the muriate becomes a chloride, which, according to Dr. J. Davy, is not volatile.

The following Acids, though producing little or no effect upon this Metal, combine with its oxide, and produce Salts; *viz.* the carbonic, boracic, phosphoric, sulphurous, molybdic, oxalic, acetic, and tartaric, which are all scarcely, if at all, soluble in water. The benzoic and succinic form soluble Salts. There is, according to Morveau, this singularity on the part of acetic Acid, that its presence prevents the precipitation of Bismuth from its nitric solution by water. The formation of the above-mentioned Salts is best effected by adding a solution of the Salt of potash with the given Acid to the nitric solution of the Metal.

(820.) L. In all the acid solutions of Bismuth, (acetic?) the addition of water produces a white precipitate, consisting of the metallic oxide generally united to a small portion of Acid; thus the white powder falling from the nitrate is an oxide containing a little nitric Acid. Prussiate of potash gives a white precipitate, and infusion of galls a yellowish one. By hydriodic Acid a chocolate precipitate, sulphuretted hydrogen a dark brown. By a plate of copper or tin a precipitate of the pure Metal is produced.

(821.) M. In the Arts, Bismuth enters in the composition of soft solders. An alloy of two bismuth, one lead, one tin, and four mercury, is used for silvering the inside of glass globes. The interior of the globe is well dried, and a small quantity of the alloy introduced; by immersion in hot water it melts, and by turning the globe about, a sufficient coating adheres to its inner surface. The flake white of painters is the precipitate from the nitrate by water, formerly called *Magistery of Bismuth*, and the pearl-white is said to be a similar precipitate from the hydrochlorate or tartrate. It is proposed to use it instead of lead in assaying.

References to § 11.

Pott, *Exercitationes Chem.* Berl. 1738; Wenzel, *Verwandschaft*; Berzelius, *An. de Ch.* vol. lxxxvii; Lagerhjelm, *An. Phil.* vol. iv.; Chaudet, *An. de Ch. et de Ph.* vol. viii.

Sect. XII.—*Copper.*

(822.) A. This Metal, occurring frequently in the native state, was one of the earliest known to the Ancients: alloyed with tin it formed the bronze of which ancient weapons were made before iron was obtained in sufficient quantity to be applied to this purpose. The armour of the warriors at the siege of Troy was of bronze, and the knives of the ancient Egyptians were found by Dr. E. D. Clarke to consist of the same alloy.

Copper is found in a state of native purity, as an oxide and sulphurets, and also as a Salt, carbonate, hydrochlorate, phosphate, sulphate, and combined with many other substances.

(823.) B. Various processes are employed for extracting this Metal from its ores. The sulphurets are roasted in reverberatory furnaces, once, or oftener, as the case may require; and, finally, reduced by heating them in an appropriate furnace with small-coal. To render it sufficiently pure for sale, it is remelted, and granulated by falling into cold water several times over; and lastly, refined by again fusing it with charcoal powder. Pure Copper for Chemical purposes is best obtained by placing a plate of iron in a slightly acid solution of Copper; the Metal is deposited in the form of a fine, brown powder, which is to be washed with a little dilute sulphuric Acid, to remove any adhering iron.

(824.) C. Copper has great brilliancy, and a fine red colour. It acts disagreeably on the organs both of smell and taste. Specific Gravity 8.60—8.89, Hatchett. It is harder than silver; has such malleability as to be beaten out into extremely thin leaves. Its tenacity is very great, according to Mr. Rennie: (*Phil. Trans.* 1818:) a wire of cast Copper, one-tenth of an inch in diameter, is broken by a weight of 190.7 pounds, and one of the same size of hammered Copper would be broken by a weight of 337.9 pounds: these results are calculated from experiments on longer bars. (Thomson.) Copper is calculated to melt at 1450° Fahrenheit, and is volatilized by increased heat. By slowly cooling it, Mongez obtained crystals in the form of quadrangular pyramids.

(825.) D. This Metal does not decompose water at ordinary temperatures, or its vapour at a red heat, but by long exposure to air and moisture a mixture of carbonate and oxide is formed upon its surface, (verdigrise.) By heating a plate of Copper to redness in atmospheric air, a red oxide is formed at the surface, and may be detached in laminæ. Two oxides of Copper are well known to Chemists, and a third is admitted by Thenard.

To obtain the lowest oxide, dissolve the Metal in hydrochloric Acid by the assistance of heat. Let this green solution be put into a phial with some metallic Copper, and cork it closely. The Liquid gradually acquires a brown colour, and deposits crystals like grains of sand. By adding hydrate of potassa to a solution of these in water, the orange-coloured oxide is precipitated. (Chenevix, *Phil. Trans.* 1806; Berzelius, *An. de Ch.* vol. lxxviii.)

The scales above described as forming upon the surface of heated Copper, are composed of the higher oxide, but retain some particles of Metal. By exposure to heat the whole becomes a uniform black powder. The same substance is obtained by precipitating a solution of Copper in nitric Acid, with a caustic, fixed alkali: and exposing the precipitate to a red heat to drive off the water.

The black oxide last described is chiefly found in the Salts of Copper, and was heretofore considered the highest oxide; but Thenard obtained, by means of an oxygenated Acid, a still higher oxide of this Metal. (a.)

If with Thomson, Prout, and Wollaston we consider the atom of Copper = 32, the constitution of these oxides will be,

	Oxygen.	Copper.
The red oxide =	8 or one atom +	64 or two atoms,
The black oxide =	8 or one atom +	32 or one atom,

forming a suboxide, and an oxide.

But if with Thenard we call the atom of Copper = 64,

	Oxygen.	Copper.
The red oxide =	8 or one atom +	64 or one atom,
The black oxide =	16 or two atoms +	64 or one atom,

forming a protoxide and a deutoxide.

Thenard could not fix the constitution of his higher oxide.

(826.) E. Chlorine readily combines with Copper-filings, forming a volatile chloride and a fixed subchloride of the Metal. These two compounds may also be obtained by evaporating the sub-hydrochlorate and the hydrochlorate of the Metal respectively.

(827.) F. Unexamined.

(828.) G. The iodide of Copper is a brown, insoluble powder, formed by adding hydriodic Acid to solutions of the Metal, or by heating Copper in contact with iodine.

(829.) H. Copper readily unites with phosphorus

Its carburet was notsupposed to exist, but Priestley obtained it by passing the vapour of alcohol through a Copper tube; the discovery is confirmed by Van Marum. (*b.*) Boron, silicon, hydrogen, and nitrogen, do not seem as yet to have been united to this Metal.

(830.) I. Alloys of Copper are of frequent occurrence in the Arts. Alloys have also been formed with potassium, sodium, arsenic, iron, (with difficulty,) nickel, cobalt, manganese, zinc, (common brass,) cadmium, tin, bismuth, and lead; but in the last case the union is so imperfect that, by heating the alloy to such a temperature as to fuse the lead, it runs out leaving the Copper nearly pure. This is curiously seen in heating Roman coins.

(831.) K. Let it be remembered that almost all the Salts of Copper contain the black oxide of the Metal. The action of nitric Acid on Copper is very violent, nitrous Gas is evolved, and the solution produces a blue crystallizable Salt. No nitrate of the suboxide exists, as by the action of nitric Acid on the suboxide, one portion of Copper falls down in the metallic state, and the other portion receiving its oxygen, a solution of the proto-nitrate remains. Without heat, concentrated sulphuric Acid has no action on Copper, but at a boiling heat the Acid is partly decomposed. Sulphurous Acid Gas escapes, and a soluble sulphate is produced. The common blue vitriol of Commerce is a bisulphate. For a description of the numerous Salts of Copper, we must refer to the more complete Systems of Chemistry.

(832.) L. Solutions of Copper are changed to a deep blue colour by addition of ammonia. Prussiate of potassa gives a reddish brown precipitate, the hydrosulphurets a black, and gallic Acid a brown one. A plate of iron throws down the Copper in the metallic state.

(833.) The uses of Copper in the Arts are so numerous and varied, that many will occur to the recollection of every one. In Medicine, the sulphate has been cautiously administered, but is an active poison; in Surgery it is employed as an escharotic.

References to § 12.

(*a.*) Thenard, *Syst.* vol. ii. p. 381. (*b.*) *An. de Ch.* vol. xxx.; Chenevix, *Phil. Trans.* 1801; Proust, *An. de Ch.* vol. xxxii. p. 26; Oxides, Berzelius, *Phil. Mag.* vol. xli. p. 200; Phosphuret, Pelletier, *Mém. de Ch.* vol. i. p. 274, and vol. ii. p. 32.

Sect. XIII.—*Tellurium.*

(834.) A. This Metal was discovered by Klaproth in one of the most productive of the ores of gold. The two Metals are found combined in the mines of Transylvania.

(835.) B. Tellurium is extracted by dissolving the gold-ore in nitro-muriatic Acid. The solution is diluted with water and pure potassa is added. Thus all the Metals are precipitated, together with a white powder, which is redissolved by an excess of the precipitant. This alkaline solution is again acidified by hydrochloric Acid; which throws down a precipitate. This powder is dried and heated with charcoal in a glass-retort. Metallic Tellurium is volatilized and forms brilliant metallic drops on the cooler surfaces of the retort.

(836.) C. In colour this Metal is between tin-white and lead-grey, with considerable lustre, and a foliated texture. Extremely light, fusible below a red heat, and very volatile.

(837.) D. When heated in the open air, Tellurium undergoes combustion and is oxidated. The oxide of Tellurium is capable of performing the parts both of a base and of an Acid; so that if space permitted a full description of its properties, we ought to place the Telluric Acid as a Subsection.

(838.) E. Tellurium unites with chlorine, forming a white Solid.

(839.) F. G. Unexamined, except that the iodide forms a red aqueous solution.

(840.) H. A combination of Tellurium with hydrogen was discovered by Sir H. Davy in 1809, and called Telluretted Hydrogen Gas. It possesses slightly acid properties, and therefore might with propriety be called Hydro-Telluric Acid Gas. It unites also with sulphur and carbon.

(841.) I. The habits of Tellurium with other Metals are little known. It has been alloyed with potassium; but does not seem disposed to unite with mercury.

(842.) K. A few of the Salts with oxide of Tellurium as a base have been examined by Berzelius; these are the sulphate, hydrochlorate, and nitrate.

The same Chemist has also examined the tellurates, and described those of potassa, ammonia, lime, barytes, copper, iron, and lead.

(843.) L. Tellurium is recognised by its volatility; by being precipitated as a white powder from its solution in nitric Acid; by giving also an orange brown precipitate with Hydrosulphuric Acid Gas.

(844.) M. None.

References to § 13.

Klaproth, Crell's *An.* vol. i. p. 91; and 1799, vol. i. p. 275; Davy, *Phil. Trans.* 1801, p. 16; Berzelius, Nich. *Jour.* vol. xxxvi. p. 129.

Sect. XIV.—*Lead.*

(845.) A. Of the first discovery of Lead we have no record, but it has been known from the very earliest times, as we find it frequently mentioned in the Mosaic writings. The Alchemists found reasons for identifying it with Saturn, under whose name they spoke of it, and by whose symbol they represented it. Lead is rarely found native, but it forms a part of several compound minerals. Its sulphate, carbonate, phosphate, chromate, and molybdate, are found in greater or less abundance; but it is from the sulphuret, (galena,) a very abundant ore, that this useful Metal is principally obtained.

(846.) B. The processes for obtaining Lead from its native sulphuret differ in some particulars, which depend upon the nature and richness of the ore. In general, the ore is triturated and washed in running water to remove as much as possible of the earthy impurities. It is then roasted to drive off a part of the sulphur, and subsequently fused with charcoal or lime, for the complete reduction of any oxide that may be formed; or for the final separation of any sulphur which may remain in combination. The galena is however often sufficiently rich in an accompaniment of silver, to make it worth while to submit it to a further process for the extraction of that Metal. It is remarked, that that galena which has a fine-grained fracture, exhibiting small, bright, curvilinear facettes, is the richest in precious Metal. (*a.*) (*b.*)

(847.) C. The colour of Lead is a bluish white.

When in fusion it is bright like quicksilver, but rapidly tarnishes and becomes covered with a crust of oxide. By exposure to air it becomes dim in a few hours, acquiring a thin surface consisting of a carbonated oxide, and then undergoes no further change. Lead can scarcely be said to make any impression on the nerves of taste, but it developes a slight smell upon friction. It produces a bluish streak upon white substances. Few Metals are less hard, for it yields to the nail. Its tenacity is by no means considerable, for, according to Mr. Rennie's experiments, a wire 25 inches in diameter supported only 114 lbs. (*c.*) The ductility of Lead is not great, though it may with care be formed into wire; and it scarcely can be said to possess any elasticity; but its malleability is rather considerable. According to Newton, the fusing point of Lead is about 540° Fahrenheit. Irvine found it 594°, (*d.*) and Crichton, of Glasgow, states it to be 612°. (*e.*) By increased heat, the Metal boils and is volatilized. By slowly cooling, it may be obtained in the crystalline form. Mongez describes these as quadrangular pyramids, and Pajot de Chormes obtained a polyhedron of 32 faces arising from the aggregation of six quadrangular pyramids. (*f.*)

(848.) D. Chemists have, in general, described Lead as uniting with oxygen in only three proportions. Berzelius, however, describes four oxides of lead.

1. The first, which he terms the suboxide, is the dark powder which gradually forms upon the surface of metallic Lead when left exposed to the air. (*g.*) Dulong obtained the same oxide by distilling oxalate of Lead to a dry powder in a glass-retort. Carbonic Acid and carbonic oxide Gases are evolved, and the suboxide remains as a dark grey powder.

(849.) 2. The next, or yellow oxide of Lead, is best obtained by precipitation from the addition of carbonate of potassa to a solution of Lead in nitric Acid. The powder as it first falls is white, but being dried, and heated nearly to redness, it takes its true yellow colour. This substance is without taste or smell, is insoluble in water, but soluble in potash or Acids. By heat it easily vitrifies, and by a considerable heat it is capable of volatilization, but if so heated with free exposure to the air the surface passes on to a red colour. (*h.*) (*i.*)

The *Massicot* of commerce, is in fact, the yellow oxide of Lead formed by exposing Lead to heat, and removing the oxide as fast as it forms upon the surface of the fused metal. This powder has at first a dusky-green colour, being a mixture of true oxide and metallic Lead, but by longer exposure to heat in an open vessel more oxygen is absorbed, and complete massicot is formed.

White Lead, so much used as a pigment, is a compound containing the yellow oxide of Lead and carbonic Acid. It is formed by exposing thin plates of Lead to the vapour of hot vinegar.

(850.) 3. The next oxide of Lead is of a bright red colour, and is known in the Arts by the name of *Minium*, or *Red Lead*. It is easily formed by exposing finely powdered massicot in such a furnace, that the flame may constantly play upon the powder which is constantly stirred so as to expose fresh surfaces. The process is continued forty-eight hours. (*k.*)

Minium is a tasteless powder of very high Specific Gravity; by exposure to a red heat it parts with a portion of its oxygen and fuses into a dark brown glass. It is acted upon by Acids, but in every case seems to undergo decomposition, and to be reduced to the state of the yellow oxide. Indeed there is no combination known in which the red oxide of Lead retains its constitution unchanged.

(851.) 4. The highest oxide of Lead is a puce-coloured powder, formed by dispersing the yellow oxide through a mass of water, and then passing a current of chlorine through the Liquid. There results a soluble hydrochlorate of Lead which may be separated by washing, and the peroxide of Lead is an insoluble powder. Such is Proust's method. It is, however, better to put one part of the red oxide (minium) into a flask with five or six parts of diluted nitric Acid, containing equal proportions of Acid and water. Heat the Liquid almost to ebullition and agitate it from time to time. Thus a soluble nitrate of the yellow oxide is formed, and the peroxide of Lead, insoluble both in water and nitric Acid. That is to say, one portion of the minium takes oxygen from the other portion, and passes to the state of peroxide, while the latter portion, being reduced to the state of massicot, (2 oxides,) forms the soluble nitrate of Lead. The oxide is to be well washed when the process is completed and carefully preserved in an air-tight phial.

The atomic constitution of these oxides of Lead present some difficulties which we have not space to discuss.

(852.) E. When Lead is placed in chlorine Gas, it does not undergo visible combustion, but the Gas is absorbed, and chloride of Lead is formed. This chloride is, however, more easily obtained by precipitation from adding a solution of common salt to a solution of nitrate of Lead. It is then found in the form of delicate, white, plumose crystals, which are, in fact, hexahedral prisms. By heat, these crystals are fused into pure anhydrous chloride of Lead: the *plumbum corneum* of early authors.

There exists also a subchloride of Lead, a white, insoluble powder, which takes a fine, yellow colour by application of heat. It is formed by decomposing a small quantity of common salt in a great excess of litharge diffused through water.

(853.) F. If hydrofluoric Acid be poured into a solution of acetate of Lead, a precipitation takes place in the form of brilliant laminæ insoluble in water, very soluble in nitric, hydrochloric, hydrofluoric Acids, and fusible at a red heat. This is considered, by some, the fluoride of Lead, and not the hydrofluate, because of its insolubility in water.

(854.) G. By heating iodine and Lead together, the iodide of Lead is readily formed. It is a fine, yellow, waxy-looking substance. The same compound is produced as an insoluble precipitate whenever a solution of any hydriodate is added to a solution of a Salt of Lead. This precipitate is of a beautiful, citron colour.

(855.) H. The combinations of Lead with azote, hydrogen, boron, or silicon, are as yet unknown.

(856.) *Carburet of Lead* is a black powder, very easy of reduction, formed by heating together a mixture of finely-powdered charcoal and oxide of Lead in a closely-luted crucible. It may also be formed by moderately heating a precipitated prussiate of Lead; in this case, nitrogen escapes and carburet of Lead remains.

(857.) *Seleniuret of Lead.* When selenion and Lead are heated together, an intimate union takes place, and more heat is evolved. A grey, porous mass is formed which is not fusible at a red heat, but is soft, and takes a silvery polish. (*l.*)

(858.) *Phosphuret of Lead* may be formed by dropping bits of phosphorus into melted Lead; or by heating in a crucible equal parts of glass of phosphorus and Lead-filings. This substance may be cut with a knife, but is not malleable. Its colour is silver-white, inclining to blue, but it tarnishes by exposure to air. (*m.*)

(859.) *Sulphuret of Lead* is easily formed by dropping pieces of sulphur into melted Lead, or by placing alternate layers of the two substances in a crucible in continued proportion, three of Lead to one of sulphur, and giving a moderate heat. Sulphuret of Lead thus formed is of a deep blue-grey colour of considerable brilliancy, less fusible than pure Lead, and very brittle. Heat does not decompose it; oxygen is not acted upon by it at an ordinary temperature; but by a moderate elevation of temperature it passes into sulphate of Lead, and sulphurous Acid, while by a further increase of temperature, a part of the Lead is reduced. This is identical with the mineral galena.

Professor Thomson states, that, " besides the common sulphuret of Lead, there occurs another occasionally, lighter in colour and more brilliant, which burns in the flame of a candle, or when put upon burning coals, emitting a blue flame. It contains at least 25 per cent. of sulphur. It is, therefore, a *Bisulphuret* of Lead. This variety has not hitherto been noticed by Mineralogists, neither has it been made artificially by Chemists." (*n.*)

(860.) I. Lead combines readily with several other Metals. When fused with *gold*, it enters into intimate combination, and when even small in quantity, it greatly impairs the colour and ductility of the nobler Metal. With *silver* it forms a very fusible compound, but of inferior tenacity and hardness. The same is true of the alloy of Lead and *platina*. The alloy of Lead and *copper* is a brittle, grey substance. It had been thought that *iron* could not be combined with Lead, but Muschenbroeck united 134 parts of Lead with 400 of iron, and formed a hard alloy, but inferior to iron in tenacity. Morveau showed, that when the two Metals are heated together, two distinct alloys are formed, the one at the top of the crucible, containing very little Lead, the other a button of iron at the bottom, but combined with a small quantity of Lead. (*o.*) This Metal readily unites with *potassium* and *sodium*. Gmelin formed the alloy of *cobalt* and Lead, by placing powder of cobalt between plates of Lead, and submitting them to heat in a crucible well covered with charcoal (*p.*) Gmelin also examined carefully the alloys of Lead and *zinc;* the Metals seem to unite in almost every proportion. (*q.*) *Bismuth* was combined with Lead by Muschenbroeck, and formed a brittle alloy. The alloy of Lead and *arsenic* is brittle, having a foliated structure. *Mercury* dissolves Lead, and the amalgam seems to retain its physical properties much in proportion to the quantities of its respective ingredients. When the Lead is in such quantity as to produce a mass nearly solid, certain crystalline facettes are perceptible.

(861.) K. Acids for the most part act upon Lead or its oxides. The Salts thus formed have a sweet taste. One oxide alone, the yellow, seems to form the base of its Salts; for if the other oxides be employed in solution, oxygen is evolved, and a Salt of the yellow oxide results.

Cold *Sulphuric Acid* has scarcely any action upon Lead, but when boiled upon it, there is an evolution of sulphurous Acid Gas, the metallic oxide is formed, and, combining with the sulphuric Acid, produces a white pulverulent substance, which is sulphate of Lead with some excess of Acid. A portion, also, is dissolved in the Acid, and may be reduced to acicular crystals, by evaporation. A neutral sulphate is, however, more regularly formed by adding a solution of any Salt of Lead to a solution of an alkaline sulphate. The white precipitate, which is sulphate of Lead, is almost insoluble in water.

(862.) *Sulphurous Acid* does not act on Lead; but if the red oxide be placed in this Acid, a saline mass is formed, consisting of both sulphate and sulphite of the yellow oxide. Sulphite of Lead is formed, also, by immersing the white oxide obtained from the nitrate in sulphurous Acid.

(863.) *Hydrochloric Acid* has but slight action upon Lead even when heated. When muriatic Acid is digested in the red oxide, the Acid is partially decomposed, as also the oxide; hydrogen from the former unites with a part of the oxygen from the latter, so that a chloride of the yellow oxide results; the excess of Acid serving as a solvent, the Salt ultimately crystallizes in delicate, silky prisms. (*Vide* E.) But to obtain this neutral muriate most readily, let a soluble Salt of Lead be added to any alkaline muriate; acetate of Lead, for instance, to muriate of soda. This Salt is soluble in 30 parts of water, and readily fuses by heat.

(864.) *Nitric Acid* forms several compounds with Lead, so as to produce rather a complicated series of Salts. Nitric Acid, slightly diluted, dissolves Lead with rapid evolution of nitrous Gas. From this solution, or from a solution of the yellow oxide in Nitric Acid, octohedral, diaphanous crystals are easily obtained. This seems to be the anhydrous nitrate of the yellow oxide. (*r.*) The other combinations of these substances have been examined by Chevreul and Berzelius, and to their Memoirs we must refer the reader. (*s.*) They are well described in Thomson's *System of Chemistry*.

(865.) *Phosphoric Acid* acts slowly upon Lead. But the phosphate of Lead, a flaky white precipitate, is easily formed by adding a solution of phosphate of soda to nitrate or acetate of Lead. This substance is insoluble in water, soluble in nitric Acid, and is decomposed by the muriatic and sulphuric Acids. Berzelius has described, also, a superphosphate and a subphosphate. (*t.*)

(866.) *Phosphite of Lead* is formed by adding a hot, concentrated solution of muriate of Lead to a solution of phosphite of ammonia, the precipitate is a flocculent, white powder.

(867.) An insoluble, white precipitate of *Borate of Lead* is formed by adding a solution of borax to nitrate of Lead.

(868.) *Carbonate of Lead* is found native, or is readily obtained by adding an alkaline carbonate to any solution of a Salt of Lead.

The oxides of Lead have never, in common language, been considered as performing the part of Acids, nevertheless they have, in general, a strong degree of affinity for the earthy oxides. Solutions of potash, or soda, will dissolve and hold in solution a portion of oxide of Lead. Lime, when boiled with it in water, does the same, and minute crystals may be obtained by evaporation. By fusion, all the earths unite with the oxides of Lead forming differently-coloured enamels; and of all the metallic oxides, that of Lead forms the strongest flux for promoting the vitrification of earthy substances. So strong is the affinity of oxide of Lead for the Acids, that it will decompose some neutral Salts when dry. Thus if oxide of Lead and muriate of ammonia be triturated together, ammonia is evolved, and by the aid of heat a complete decomposition may be effected. Muriate of soda is capable of a similar decomposition.

(869.) L. Numerous characteristics distinguish Lead and its Salts; the latter, if soluble at all, give a colourless Liquid. They have a sweet taste, and are strongly styptic. Hydrosulphuret of potash, sulphuretted hydrogen, and, in short, sulphur in any of its forms, produces a copious black or deep-brown precipitate. Prussiate of potash, gallic Acid, and infusion of galls, all produce white precipitates. Zinc precipitates the Lead in a pure, metallic state. Sulphate of soda is used as a test of Lead producing a white precipitate. Hydriodate of potash produces a beautiful, bright, yellow-coloured precipitate. Vauquelin has shown that the precipitates thrown down from the Salts of Lead by the alkalis are subsalts. (*u.*) The most satisfactory proof that a precipitate contains Lead, is obtained by reducing it by the blow-pipe on charcoal. The polyhedral form which the irreducible, enamel-looking globule assumes upon cooling, after it has been fused by the blow-pipe on charcoal, is a good proof of Lead which has been precipitated by a phosphate.

"The uses of Lead are extensive. As it is flexible, easily reduced to thin sheets, and easily united by solder, it is used in making pipes for conveying water, large boilers, and vessels of different kinds. It is cast into thin sheets for covering buildings. Its oxides are used as paints. They are also employed in the manufacture of the finer kinds of glass, to which they communicate density, a higher refractive power, a greater equality of texture, and a greater susceptibility of polish: hence, they enter into the composition of the pastes which imitate gems. They form, in combination with earthy matter, the glazing of the inferior kinds of earthenware. There is some reason to doubt, whether the use of Lead in pipes for conveying water, or in vessels for containing it, be altogether safe; Lead, immersed in water, is covered at length with a white crust of oxide or carbonate; and this Metal is the most insidious, and, at the same time, one of the most destructive of the mineral poisons. In water, however, which has been conveyed through pipes of Lead, no trace of the Metal can be discovered by the most delicate test, sulphuretted hydrogen. Even water kept in cisterns of Lead, where the exposure to the air is more free, seems not to have, in general, any sensible impregnation; this may arise from the deposite of earthy matter from the water covering the Lead. The observations of Guyton too, on the effect of the presence of a little saline matter in preventing its action on Lead, may serve to explain how the practice of keeping water which is used as drink in cisterns of Lead, is not more injurious than it appears to be. Some facts appear to prove, that river water is more liable to receive an impregnation from leaden vessels than spring water is, probably from the Salts in the former being chiefly muriates, while in the latter they are sulphates or carbonates. The use of earthenware glazed with oxide of Lead is hazardous, as the glazing is soon eroded by any acid liquor, and a noxious impregnation communicated; and many fatal accidents have occurred from the use of Lead in the fabrication of vessels in which wine, cider, and other fermented liquors, are prepared or kept."

Minium and massicot have been already noticed. (D.) *Litharge*, another common preparation of Lead, is supposed to contain the yellow oxide, with, perhaps, the admixture of some carbonic Acid; it is formed during the process of cupellation by directing a strong current of air upon the surface of the fused Lead which thus carries off the oxide in a semivitrified, or crystalline state, in fine scales as fast as it is formed. If litharge be fused by a stronger heat into a compact mass, it goes by the name of *Glass of Lead.*

In consequence of the sweet taste of the Salts of Lead, they have at times been employed to correct the flavour of bad wines. This most pernicious adulteration is readily detected by what is generally called *Hahneman's Wine Test*, having the advantage of precipitating Lead but not iron. "It is prepared from sulphuret of lime (formed by exposing equal parts of sulphur and oyster-shells to a white-heat for 15 minutes) and supertartrate of potash. 120 grains of the sulphuret and 180 of the supertartrate are put into a bottle, which is to be filled with 16 ounces of water that has been previously boiled and suffered to cool. The liquor having been repeatedly shaken, is to be poured off clear into phials which hold about one measured ounce; into each of which about 20 drops of muriatic Acid has been put; and they are well corked. One part of this solution mixed with three parts of the suspected liquor will discover, by a black precipitate, the smallest quantity of Lead, while it does not precipitate iron; the tartaric and muriatic Acids retaining iron in solution when combined with sulphuretted hydrogen." (*v.*) Burgundy, and all wines which hold tartar in solution, will not retain an adulteration of Lead, as the tartrate is insoluble. Lead taken internally is an active poison. Small quantities of the acetate are sometimes given as a styptic in cases of internal hemorrhage. Its solution is employed as a sedative application to inflamed surfaces and scrofulous sores. When greatly diluted, it forms a good eye-water. *Goulard's Extract*, the subacetate, is indeed a valuable article in Pharmacy. The deleterious effects of Lead may be seen in the specific disease which afflicts house-painters, and has the name of *Colica Pictonum.* A disease much similar prevailed formerly in the cider Countries, from placing the cider in leaden vats. Its evil effects are chiefly of a paralytic form, when taken for some time in small quantities. A large dose will act as a poison: the best antidote for any one that cannot be ejected from the stomach, is a quantity of sulphate of soda dissolved in water.

References to § 19.

(*a.*) Aikin, *Ch. Dict.* art. Silver. (*b.*) Nicholson, *Jour.* vol. xv. p. 1. (*c.*) *Phil. Trans.* 1818, p. 126. (*d.*) *Chemical Essays*, p. 35. (*e.*) *Phil. Mag.* vol. xvi. p. 49. (*f.*) *Jour. de Ph.* vol. xxxviii. p. 53. (*g.*) *An. de Ch.* vol. lxxxvii. (*h.*) Bucholz, Gehlen's *Jour.* vol. v. p. 259. (*i.*) Berzelius, *An. de Ch.* vol. lxxviii. p. 11, and vol. lxxix. p. 121. (*k.*) Watson, *Essays*, vol. iii. p. 338. (*l.*) Berzelius, *An. de Ch. et de Ph.* vol. x. p. 245. (*m.*) Pelletier, *An. de Ch.* vol. xiii. p. 114. (*n.*) *Syst.* vol. i. p. 449, Ed. 6. (*o.*) *An. de Ch.* vol. lvii. p. 47. (*p.*) *An. de Ch.* vol. xix. p. 357

(*q.*) *An. de Ch.* vol. ix. p. 95. (*r.*) Thomson, Nich. *Jour.* vol. viii. p. 283. (*s.*) *An. de Ch.* vol. lxxxiii. p. 1, 57, vol. lxxxiv. p. 1. (*t.*) Berthier, *Jour. de Mines*, No. 132; Berzelius, *An. de Ch. et de Ph.* vol. ii. p. 160. (*u.*) Nich. *Jour.* 4to. vol. iii. p. 473. (*v.*) Crell's *Chem. Jour.* vol. iii. p. 61.

METALS. CLASS V.

Sect. I.—*Mercury.*

(870.) A. The early history of this Metal is entirely involved in the obscurity of distant Ages. Its uses in the separation of other Metals are among the earliest recorded metallurgic processes. (*a.*)

(871.) B. The ores of Mercury are numerous. The process by which the pure Metal is chiefly obtained is by putting the richest ore, carefully picked, into retorts with some lime just slaked by exposure to air. Heat is applied, and the Mercury is condensed in a cool receiver.

(872.) C. This is the only Metal permanently fluid at our ordinary atmospheric temperatures. It freezes at − 39°, or − 40° Fahrenheit; at 680° on the common Mercurial scale, or 662° on that scale corrected, it boils, and rapidly distils over. Its vapour has high expansive force.

(873.) D. Mercury undergoes oxidation by agitation in a bottle with atmospheric air. The oxide so formed was called *Æthiops per se*, by Boerhaave. This black oxide is, however, better obtained by boiling calomel with an excess of caustic alkali in solution.

Another oxide is formed by exposing the Metal, for several days, to a high temperature, in a flat glass-vessel freely exposed. The red oxide so obtained was formerly called *Precipitate per se.* The oxides of Mercury are reduced by mere exposure to heat in a retort. The two oxides of Mercury are true protoxide and deutoxide.

(874.) E. Mercury readily forms two chlorides. *Calomel* is the protochloride, and *Corrosive Sublimate* the deutochloride of this Metal.

(875.) F. Unexamined.

(876.) G. There are two iodides of Mercury. The protiodide is formed by mixing a solution of the protonitrate of Mercury with the hydriodate of potassa. The deutiodide by mixing the same hydriodate with a solution of any deuto-salt of Mercury.

(877.) H. Mercury combines with sulphur, forming a sulphuret and bisulphuret. The latter, known by the name of *factitious Cinnabar*, is formed by fusing sulphur with six times its weight of mercury, and collecting the sublimate produced in close vessels. When reduced to fine powder, this same substance is *Vermilion. Æthiops Mineral* is formed by triturating together equal parts of Mercury and sulphur. Mr. Brande has shown that it is a mixture of sulphur and bisulphuret of Mercury. (*b.*)

(878.) I. Of these substances, selenion alone has been combined with Mercury.

(879.) K. The sulphuric, nitric, and some other Acids dissolve Mercury. Two distinct classes of Salts are formed by its respective oxides. In a more extended Treatise these ought all to be described. Here, however, that is not possible; and as it is obvious to the reader, that in thus abbreviating our description of this Metal, we are treating of it far less fully than many of the other Metals, and especially than that described in the last section, we state once for all, in apology to those who may make the remark, and with justice, that the inequalities of that sort, which are considerable in this Treatise, arise from circumstances which the author has not been able to control.

(880.) We must not, however, omit to notice a curious detonating compound of Mercury described by Mr. Howard. (*c.*) It is formed by dissolving 100 grains of Mercury in a fluid ounce and half of nitric Acid, of Specific Gravity 1.3; and when cold, pouring the solution gradually into two ounces of alcohol, Specific Gravity 0.849. The mixture is then to be gently heated in a flask, or retort, over a lamp, till a brisk effervescence ensues. A dun-coloured precipitate falls down, which is to be most carefully dried over a water-bath; and this is the fulminating Mercury. This compound will bear a heat somewhat above 212° without explosion; but any further elevation of temperature, or friction with hard substances, or percussion, occasions instant and violent explosion. From silver, a similar, but still more violent compound is obtained. See Fulminating Powders in our *Miscellaneous Division.* M. Liebig proved, (*d.*) that this substance is a Salt containing a peculiar Acid; and MM. Gay Lussac and Liebig have made a further analysis of that Acid. (*e.*) From their experiments, the Acid appears to consist of cyanogen and oxygen, so as to be a true cyanic Acid.

(881.) L. Solutions containing Mercury give a white precipitate with prussiate of potassa, a black one with hydrosulphates; a white one with hydrochloric Acid; orange-yellow with gallic Acid; and a plate of copper throws down the Metal pure. A neat test of Mercury is mentioned in the very valuable Work on Medical Jurisprudence by Paris and Fonblanque. Place a drop of a Liquid, suspected to contain Mercury, on a polished plate of gold. Touch the moistened surface with the point of a knife; if Mercury be present, the point touched instantly becomes white from the formation of an amalgam of Mercury and gold.

(882.) M. Mercury has many uses in the Arts, in Metallurgic processes, and in Medicine.

References to § 1.

(*a.*) Watson's *Chemical Essays.* (*b.*) *Journal of Science*, vol. xviii. p. 294; also Guibourt, *An. de Ch. et de Ph.* vol. i. (*c.*) *Phil. Trans.* 1800. (*d.*) *An. de Ch. et de Ph.* vol. xxiv. (*e.*) *An. de Ch. et de Ph.* vol. xxv.; Donovan, *An. Phil.* vol. xiv. p. 244; Sefstrom, *An. Phil.* vol. iii. p. 335; Payssé, *An. de Ch.* vol. li. p. 202. Bergman, *Opusc.* vol. iv. p. 281; Rose, Gehlen's *Jour.* vol. vi. p. 28; Zaboada, *Jour. de Ph.* vol. lx. p. 383; Davy, *Phil. Trans.* 1811, p. 26; Pelletier, *An. de Ch.* vol. xiii. p. 122; Gay Lussac and Thenard, *Rech.* vol. i. p. 222.

Sect. II.—*Nickel.*

(883.) A. Nickel was first recognised as a distinct Metal by Cronstadt in 1751, and his experiments were confirmed by Bergman in 1775. Kupfer-nickel, *false copper*, was the minor term for the ore, and the latter word was retained by Cronstadt as its distinctive name. It is found as a very impure metallic alloy, and in the state of an oxide. It is also considered the colouring matter of Chrysoprase.

(884.) B. The analysis of Kupfer-nickel is complicated, but an easy method of obtaining the pure Metal is proposed by Thomson. Dissolve the Nickel of Commerce (speiss) in sulphuric Acid, adding a small quantity of nitric Acid to promote oxidation. By concentration, green crystals of sulphate of Nickel are obtained; and, for further purification, some of the first formed and purest are washed, and again dissolved in water, and submitted to a second crystallization. By adding an alkali to a solution of these in water, pure oxide of Nickel is obtained. Let this be mixed with three per cent. of resin, formed into a paste with oil, and exposed to a forge-heat in a charcoal crucible, a button of pure metallic Nickel is obtained.

(885.) C. Pure Nickel is nearly as white as silver, but with a slight cast of yellow. It is malleable, and rather softer than iron. Its Specific Gravity, when fused, is 8.03, but by hammering it, it is brought to 8.82. Its fusing point is at least 160° of Wedgewood. Nickel possesses permanent magnetic properties, and, according to Lampadius, its energy is to that of iron as 35 to 55.

(886.) By exposure to heat, Nickel tarnishes but does not oxidate. If, however, the Metal is dissolved in nitric Acid, the precipitate given by potassa after exposure to a red heat, is the protoxide and of a bluish-brown colour. Thenard obtained the next, a hemideutoxide, by passing a current of chlorine through water holding protoxide of Nickel suspended in it; a portion is dissolved, and the remaining black powder is the hemideutoxide of this Metal.

(887.) E. Nickel does not instantly combine with chlorine, but by leaving the substances in contact, a chloride may be formed; a more ready process, however, is to expose the muriate to a red heat.

(888.) F. Unknown.

(889.) G. The iodide of Nickel, a greenish precipitate, is formed by adding hydriodate of potassa to a solution of the sulphate or nitrate of the Metal.

(890.) H. Nickel has been united to sulphur, phosphorus, selenion, and carbon, but does not combine with nitrogen or hydrogen. Of its habitudes with boron, or silicon, we are ignorant.

(891.) I. Nickel combines with gold, copper, tin, and arsenic, forming brittle alloys, but its compounds with silver and iron are ductile. Arsenic entirely destroys its magnetic properties, as it also does those of iron and cobalt.

(892.) K. Both Nickel and its oxides are readily soluble in nitric Acid with heat, and a nitrate is obtained in rhomboidal prisms, which, according to Bergman, first deliquesce, and finally effloresce, and fall to powder. Proust describes a subnitrate also, and Thenard a double nitrate of Nickel and ammonia.

Sulphuric Acid dissolves the oxide, and also the Metal; if aided by the addition of a few drops of nitric Acid the sulphate readily crystallizes. Sulphate of potash and Nickel, of ammonia and Nickel, and of iron and Nickel, have also been described.

Hydrochloric Acid scarcely attacks the Metal, but dissolves the oxide, and a crystalline hydrochlorate is produced, with properties like those of the nitrate. The following Acids do not attack the Metal, but produce precipitates of insoluble Salts, on the addition of their neutral Salts to neutral solutions of Nickel. Carbonic, phosphoric, (and this has a slight action on the oxide,) boracic, selenic, (but the biseleniate is soluble,) and molybdic.

The oxalic Acid attacks Nickel if slightly heated, and a greenish, insoluble oxalate is deposited. It may also be produced by dropping oxalic Acid into a Salt of Nickel in solution. Acetic Acid also dissolves Nickel, and a very soluble Salt results. No precipitate is produced by adding benzoate or succinate of ammonia to solutions of Nickel; hence these Salts are considered soluble. The arseniate also is soluble; but the chromate, formed by suffering chromic Acid to act upon the carbonate, gradually deposits itself in a pulverulent form.

All the Salts of Nickel are of a green colour, and appear to contain the protoxide, which is also soluble in ammonia. On this property Thenard has founded his process for separating Nickel from cobalt. (*An. de Chim.* vol. l.) A solution of the two Metals is precipitated by an alkaline carbonate. By the addition of oxymuriate of lime, the cobalt is converted into the peroxide. Ammonia will now take up the oxide of Nickel only, which may be regained by evaporation.

Nickel is soluble also in ammonia.

(893.) L. In neutral solutions of Nickel, hydrosulphuric Acid Gas produces no change, but hydrosulphate of potash gives a black precipitate. Prussiate of potash, a white or greenish one; and infusion of galls gives, with some Salts, a grey precipitate, but, according to Thomson, with the sulphate none at all. The caustic alkalis produce white, and their carbonates apple-green precipitates. No Metal produces one precipitation.

(894.) M. The only purpose to which Nickel has been applied is in the formation of magnetic needles, for which, if plentiful, it might sometimes be useful where steel would rust. From some recent experiments of Stodart and Faraday, *Quarterly Journal*, vol. ix., the alloy of Nickel and iron would be serviceable in the Arts, being less liable to rust than common iron; but it is singular that Nickel alloyed with steel increases the tendency to rusting. By far the greater part, and, until lately, it was thought that all the meteoric stones which have fallen from the atmosphere contained Nickel. Laugier (*Mém. de Muséum*, vol. vi.) asserts chromium to be a more constant ingredient; but, be this as it may, several masses of native metallic iron, which from their situation upon the surface of the earth appear to be of meteoric origin, contain more or less Nickel. The blades of the knives used by the Esquimaux tribe, found in the late Northern voyages of discovery, were of this kind.

References to § 2.

Cronstadt, *Stockholm Trans.* 1751 and 1754; Berg. *Opusc.* vol. ii.; Fourcroy, *Disc. Prélim. Ecole de Mines*; Bucholz, Gehlen's *Jour.* vol. ii. and vol. iii.; Richter, Gehlen's *Jour.* vol. iii.; Tourte, Gehlen's *Jour.* vol. vii.; Phillips, *Phil. Mag.* vol. xvi.; Proust, *Jour. de Phys.* vol. lvii.; Thenard, *An. de Ch.* vol. l.; Proust, *An. de Ch.* lx.; Tupputi, *An. de Ch.* vol. lxxviii.; Lampadius, *An. Phil.* vol. v.; Tupputi, *An. de Ch.* vol. lxx.; Laugier, *An. de Ch. et de Ph.* vol. ix.; Berthier, *An. de Mines*, vol. iv.; and *An. de Ch. et Ph.* vol. xiii.

Sect. III.—*Osmium.*

(895.) A. Osmium was so called by Professor Tennant from the peculiar and pungent smell (ὀσμή) of its volatile oxide. This smell, according to Fourcroy and Vauquelin, is similar to that of chlorine; and to their examination of this substance we owe some information, though they confounded this Metal and iridium together. The existence of this Metal in a native alloy with iridium, among the grains of crude platinum, has been already noticed.

(896.) B. To obtain metallic Osmium, the alkaline solution mentioned in the section on iridium, is to be mixed with sulphuric Acid, and submitted to distillation. The oxide of Osmium passes over with some water; metallic mercury is agitated with this solution, and abstracts to Osmium, forming an alloy. By subsequent distillation, the mercury is separated, and the Osmium remains.

(897.) C. Osmium is a dark-grey powder, and as it has never yet undergone sufficient heat to reduce it to a mass, its physical properties are quite unknown.

(898.) D. When Osmium is heated with exposure to air, it oxidates and sublimes, but it is very probable that the pure Metal is not volatile. Oxide of Osmium may be readily procured by mixing the black powder with nitre, and distilling at a low heat. Oxide of Osmium rises into the neck of the retort in the form of an oily fluid, which by cooling becomes a solid, semitransparent mass, soluble in water. According to Vauquelin, pure oxide of Osmium exists in the form of transparent crystals, having a strong and caustic taste. Very soluble in water, and capable of blackening animal and vegetable substances. There is strong reason for suspecting that oxide of Osmium enters into combination with alkalis.

(899.) E. With chlorine, Osmium combines, appearing at first to melt, and assuming a green colour, and, finally, forming a brownish-red liquid.

(900.) F. G. H. Unknown.

(901.) I. Osmium has been alloyed with gold and copper.

(902.) K. On this head also very little is known by direct experiment. According to Tennant, Osmium resists the action of all Acids; but according to Vauquelin, it is soluble in the hydrochloric and nitro-muriatic; but of any Salts with oxide of Osmium as a base, we are as yet ignorant.

(903.) L. Solutions of oxide of Osmium become yellow by the addition of ammonia and carbonate of soda. Magnesia produces no effect, but potassa and lime produce yellow precipitates. The most striking test of Osmium is infusion of galls, which produces a blue colour in solutions of this Metal. If iridium also is present, the infusion of galls first destroys the red colour of the iridium in solution, and then developes the beautiful blue of the oxide of Osmium. Copper, tin, zinc, and phosphorus cause a metallic precipitation.

(904.) M. None.

References to § 7.

Tenant, *Phil. Trans.* 1804; Fourcroy and Vauquelin, *An. de Ch.* vol. l.; Vauquelin, *An. de Ch.* vol. lxxxix.

METALS. CLASS VI.

Sect. I.—*Silver.*

(905.) A. Silver has been known and employed from the very earliest times. There are several ores of Silver in which it is combined with sulphur, with hydrochloric Acid, with antimony, arsenic, and mercury. It is also found native, but not in a state of perfect purity, and from this source the first knowledge of the Metal would probably arise.

(906.) B. The rich ores of native Silver found at Konigsberg, are fused with an equal weight of lead, by which an alloy is formed, and finely purified by cupellation. The Freyberg ores, which contain but little Silver mixed with much pyrites, are mixed with common salt and roasted in the reverberatory furnace. The frit is then pulverized and washed; and by the addition of mercury an amalgam is formed, which is drained from the earthy and saline matters. It is then submitted to pressure in a bag, by which means the liquid mercury is separated, and the more solid alloy remains for final purification, by distilling off the remaining mercury in heated earthen retorts. In Mexico and Peru the process is nearly the same.

Silver is also obtained in considerable quantities from some varieties of galena, native sulphuret of lead.

For Chemical purposes, pure Silver is best obtained by a process recommended by M. Gay Lussac. (*a.*) Precipitate the Silver from its nitrate by a plate of copper; digest the precipitate in a weak solution of nitrate of Silver; by which any adhering copper is taken up, and pure Silver deposited in its place.

(907.) C. Silver is the whitest Metal at present known, and capable of receiving a very high degree of brilliancy from the burnisher. It has neither taste nor smell. Its hardness is superior to that of copper, but inferior to that of gold. Its Specific Gravity 10.39—10.51. Its ductility and tenacity are of the highest order, and in malleability it is inferior to gold only. It may be beaten out into leaves of one hundred-thousandth of an inch in thickness. It fuses at a full red heat, which has been estimated at about 1000° Fahrenheit, or according to Dr. Kennedy, at 22° Wedgewood. By a greatly increased heat, it is capable of volatilization. This is effected either by the flame of oxygen and hydrogen from the Gas blowpipe, or as Vauquelin found, by a current of oxygen alone upon charcoal. By slow cooling and pouring off some portion while still fluid, four-sided pyramidal crystals may be produced.

(908.) D. By exposure to the air or to water, Silver does not undergo oxidation, but by long continued heat in an open vessel it may be converted into a greenish-brown oxide: Galvanic Electricity and the common Electric discharge produce the same effect. The same oxide is produced by precipitating a solution of Silver in nitric Acid with lime-water. This oxide is insoluble in water, but soluble in several Acids, and in ammonia.

If the ammoniacal solution of this oxide be exposed to the air, a pellicle, consisting of a black powder, forms upon the surface, which Mr. Faraday considered a peculiar oxide; and from a repetition of his experiments, Dr. Thomson coincides with him in opinion.

(909.) E. When Silver is heated in chlorine, the Gas is gradually absorbed, and a chloride of Silver is obtained. It is easily formed also by adding any hydrochlorate, or a solution of chlorine, to a solution of nitrate of Silver, in which cases it instantly forms a white, curdy precipitate. This substance, formerly called muriate of Silver, is fused into a greyish mass, but undecomposed at a red heat; and this is the *horn Silver* of older Chemists and Mineralogists. It is soluble in ammonia, and decomposed by alkaline carbonates, while the pure alkalis and Acids have no effect upon it. Being a most definite compound, it is the usual state in which Silver is separated in analysis; and after a low red heat, its weight affords, by calculation, an accurate estimate of the Silver acted upon. The chloride is easily reduced, by fusion in a crucible with twice its weight of carbonate of potash or soda, a button of pure Silver resulting. It is also decomposed by trituration, or fusion with several of the Metals. (*b.*)

(910.) F. Unexamined.

(911.) G. By adding hydriodic Acid to a solution of nitrate of Silver, iodide of Silver is precipitated; it is yellow, insoluble in water or ammonia, but is decomposed by heating it with potash.

(912.) H. Silver does not combine with azote, hydrogen, carbon, boron, or silicon. Pelletier formed its phosphuret; and Berzelius is of opinion that two seleniurets exist. Silver appears to have a strong affinity for sulphur; the sulphuret is found native, and forms the tarnish which is so frequently seen upon Silver plate; this arises from the hydrosulphuric Acid Gas, which is produced by the decomposition of animal and vegetable matter daily going on. The discoloration of a tea-spoon with which an egg has been eaten, arises from the same cause.

(913.) I. Silver is alloyed with copper, for coinage, in England and most other Countries. It unites with iron, but with slight energy, for in cooling rapidly, globules of Silver are forced as it were from pores in the mass; and by slow cooling, the Metals are almost entirely separated in the order of their Specific Gravities, a mass of iron being found at bottom and Silver at the top. The same takes place with cobalt. Silver produces brittle alloys with zinc, arsenic, bismuth, lead, and tin; malleable ones with gold, copper, platinum, and mercury.

With nickel it refuses to unite.

(914.) K. Silver is acted upon by some of the Acids, but not by all. In the nitric, it is readily soluble, with the evolution of nitrous Gas. This solution gives to the skin, and to all animal matter, an indelible black stain. It is capable of crystallization, is soluble in alcohol, and a part of its Silver is reduced by exposure to light. It is decomposed by a red heat, and when fused by a moderate degree of heat, and cast into moulds, forms the common lunar caustic.

Sulphuric Acid acts on Silver only when heated, but at the same time the Metal must be in a minute state of division. Phosphoric Acid does not act on Silver, but the phosphate may be indirectly obtained. For a full description of the Salts of Silver, we must refer to more extended Treatises.

(915.) L. For the most part, the Salts of Silver are very sparingly soluble in water. They may be reduced, before the blowpipe, in charcoal. Solutions of Silver are precipitated by muriatic Acid, or the muriates. By sulphate of iron, the Silver is precipitated in the metallic state. By a plate of copper, the Metal is thrown down nearly pure. Prussiate of potash gives a white, and the alkaline hydrosulphurets a black precipitate. In some of the saline solutions of Silver, according to Thomson, gallic Acid causes a yellowish-brown precipitate.

(916.) M. The alloy of Silver with copper for coinage in England, is 11.1 of Silver to $\frac{9}{10}$ of copper. The best Silver plate is formed by uniting a plate of copper to the surface of a thin plate of Silver, and then extending the mass by passing it between steel rollers, after which it is ready to be worked up into various ornamental and useful forms. Inferior plate is manufactured by applying an amalgam of Silver to the surface of the copper, after some adhesion is effected; the mercury is driven off by heat, and the Silver undergoes the operation of the burnisher. The brass dials of clocks, thermometer and barometer scales, &c. are silvered by rubbing upon them a mixture of whiting, pearlash, and chloride of Silver. A similar composition is often sold in small balls in the streets of London for beautifying old brass candlesticks. According to Stodart and Faraday, (*Quarterly Jour.* vol. ix.) an alloy of one part of Silver with 500 of steel is admirably adapted for the manufacture of cutting instruments. *Indelible marking ink* is made by dissolving ten grains of lunar caustic in half an ounce of gum-water; with this ink, the linen is to be marked from a common pen, but to prevent the corrosive quality of the salt it is necessary to moisten the linen with a weak solution of pearlash, which is suffered to dry before the ink is applied. It is a singular fact that if, instead of potash, soda be the alkali employed, the ink runs.

The *Arbor Dianæ*, a beautiful experiment of the Alchemists, is formed by putting into a flask six drachms of a saturated solution of nitrate of Silver, and four drachms of a saturated solution of nitrate of mercury, diluted with five ounces of distilled water; in this solution place a small lump of amalgam, consisting of seven parts of mercury with one of Silver. The flask is to remain perfectly quiet, and in a few hours a beautiful arborescent precipitate is produced.

Two very violent fulminating compounds of Silver are known to Chemists. The first was discovered by Berthollet, (*An. de Chim.* vol. i.) and is thus formed. Precipitate a solution of nitrate of Silver by lime-water. Wash the brown oxide thus produced in the open air, and let it be kept dry in a well-closed phial. To prepare the fulminating compound, put ten or twelve grains of this oxide into half an ounce of ammonia perfectly caustic, and moderately dilute. The oxide blackens, and more or less is dissolved. Pour the clear solution into a shallow vessel, and expose it to the action of the air. In ten or twelve hours, the surface becomes covered by a crystalline pellicle, which is the fulminating Silver. This formidable substance is to be removed while still wet, in lumps not exceeding two grains, to bits of blotting-paper, and suffered to dry. Even when wet, it will sometimes explode by a touch, and when dry the touch of a feather, or a bristle, will ignite it; the black powder which remains in the solution appears to possess the same properties; and so violent and uncertain is the action of this substance, that it is one of the last experiments we should advise a beginner to undertake.

The other fulminating Silver, though of great power, may be procured with more safety. The process for its formation is described in Art. (880.) See also FULMINATING POWDERS, in our *Miscellaneous Division.*

References to § 1.

(*a.*) *An. de Ch.* vol. lxxviii. (*b.*) Margraaf, *Opusc.* vol. i. and Faraday, *R. I. Jour.* vol. viii.; Lewis, *Com. Phil. Techn.*; Proust, Nich. *Jour.* vol. xv.; Thomson, *An. Phil.* vol. iv.; Faraday, *Quarterly Jour.* vol. iv.; Proust, *Jour. de Phys.* vol. xlix.; Rose, Gehl. *Jour.* vol. vi.; Marcet, Nich. *Jour.* vol. xx.; J. Davy, *Phil. Trans.* 1812; Coulomb, *An. de Ch.* vol. xliii.; Thomson, Nich. *Jour.* vol. xiv.; Fulhames, *Essay on Com-*

bustion; Brugnatelli, *An. de Ch.* vol. xxvii.; Gay Lussac, *An. de Ch.* vol. lxxviii.; Vauquelin, *An. de Ch.* vol. lxxxix.

Sect. II.—*Palladium.*

(917.) A. Palladium was obtained by Dr. Wollaston in 1803, from crude platinum, with which it exists as a native alloy, and also in separate grains, having a radiated structure.

(918.) B. The most simple process for obtaining it is by the addition of prussiate of mercury to a solution of crude platinum, one thousand parts of crude platinum containing seven of Palladium; a flocculent, yellowish-white precipitate of prussiate of Palladium is formed, which is easily reduced by heat to the metallic state.

(919.) C. This Metal is nearly white, and has much the appearance of platinum. It is harder than wrought iron. Its Specific Gravity has been stated from 11.3 to about 12.14. It is malleable, and not very elastic. By exposure to heat and air, it undergoes no change. Its fusing point is somewhat below that of platinum. When strongly heated, its surface receives a blue tarnish by which it may be distinguished from platinum.

(920.) D. The only known oxide was formed by Berzelius, who heated the filings of the Metal with potash and a little nitre. Its colour was chestnut-brown.

(921.) E. The chloride of this Metal has not been examined.

(922.) F. G. Unknown.

(923.) H. Sulphur unites with Palladium.

(924.) I. Palladium has been alloyed with several other Metals.

(925.) K. Sulphuric Acid does not act freely on this Metal; but when boiled upon it, some little is taken up, and a blue solution formed. Nitric Acid has rather more power, and forms a beautiful, red solution. Hydrochloric Acid, by aid of a boiling heat, produces a fine red solution. But nitro-muriatic Acid is the proper solvent of Palladium.

This Metal unites also with potassa and soda by fusion. Ammonia seems also capable of dissolving a small portion of the Metal.

(926.) L. Solutions of Palladium have usually a red colour. Ferro-hydrocyanate of potassa gives an olive-coloured precipitate. Hydrosulphuret of potassa a dark-brown one. The alkalis an orange precipitate. By mercury and sulphate of iron, the Metal is precipitated in the metallic state. Hydrochlorate of tin changes a very dilute solution to a fine emerald-green colour, but in a concentrated solution produces a brown precipitate. Hydrochlorate of ammonia produces no precipitation; thus distinguishing Palladium from platinum.

(927.) M. The scarcity of Palladium has prevented its general application to any purpose in the Arts; except that Mr. Troughton graduated the celebrated mural circle at Greenwich upon an alloy of gold and Palladium, furnished by Dr. Wollaston, but he does not consider that gold alone would be inferior.

References to § 2.

Chenevix, *Phil. Trans.* 1803; Wollaston, *Phil. Trans.* 1804 and 1805; Vauquelin, *An. de Ch.* vol. lxxxviii.; Berzelius, *An. Phil.* vol. iii. and *An. de Ch. et de Ph.* vol. x.

Sect. III.—*Rhodium.*

(928.) A. Rhodium was discovered in 1803, by Dr. Wollaston, with palladium in crude platinum, which contains about four parts in one thousand of this Metal.

(929.) B. Dr. Wollaston's process for obtaining it is this. Expel the mercury from crude platinum by a red heat; digest upon the Metal a small quantity of nitro-muriatic Acid to remove the gold. Dissolve in dilute nitro-muriatic Acid, digesting it in a sand heat in such a manner that a portion may remain undissolved, and the Acid be perfectly saturated. The greater part of the platinum may be precipitated by a hot solution of hydrochlorate of ammonia. By immersion of a plate of zinc the iron remains in solution, and a black powder falls, containing platinum, palladium, Rhodium, copper, and lead. The last two Metals may be removed by dilute nitric Acid. After again forming a solution by nitro-muriatic Acid, a small quantity of hydrochlorate of soda is added, and the whole evaporated to dryness; alcohol then removes every thing, leaving the hydrochlorate of Rhodium undissolved. By solution in water, and again immersing a plate of zinc, a black powder is precipitated, which, after heating with borax, assumes the metallic appearance, but does not enter into fusion.

(930.) C. Iridium excepted, this is the most infusible of Metals. Dr. Wollaston was unable to obtain from the grains a compact, metallic button, but Dr. Clarke produced, by the heat of the Gas-blowpipe, a small and malleable bead of this very refractory substance. Its colour is white, and in hardness it rather exceeds iron. Its Specific Gravity is 11. or perhaps rather less.

(931.) D. According to Berzelius, there are three oxides of this Metal: a black one formed by exposing the Metal to heat with access of air; another, formed by heating powdered Rhodium with potassa and a little nitre, is of a brown colour; and a third, which is obtained by precipitation from the soda-muriate by potash, exists in the state of a hydrate. By heat, the water and a part of the oxygen is driven off, and an inferior oxide remains.

(932.) E. Of the action of chlorine we know nothing; but as a Salt may be formed by the hydrochloric Acid, it is probable that a chloride may exist.

(933.) F. G Unascertained.

(934.) H. With sulphur, Rhodium very readily unites, but with other substances of this class its properties are unknown.

(935.) I. Dr. Wollaston found that this Metal combined with all Metals that he tried except mercury.

(936.) K. Rhodium resists the action of all Acids; but Dr. Wollaston found the highest oxide soluble in all the Acids that he tried. He describes a nitrate and a sulphate, obtained by an indirect process.

Oxide of Rhodium readily forms double Salts with hydrochloric Acid and alkalis; which Salts are insoluble in alcohol.

(937.) L. Solutions and Salts of Rhodium have a beautiful red colour, and from this property the Metal derives its name (ροδειος, rosy.) No precipitate is produced by prussiate of potassa, nor by the hydrosulphates. The alkaline carbonates give no precipitate, but the pure alkalis give a yellow one soluble in excess of the alkali.

(938.) M. In the Arts, Rhodium would probably, from its hardness, prove eminently useful, if it were more plentiful. Messrs. Stodart and Faraday speak highly of its properties, in their experiments on metallic alloys.

References to § 3.

Wollaston, *Phil. Trans.* 1804; Descotils, *Jour. de Ph.* vol. lxi.; Berzelius, *An. Phil.* vol. iii.; Vauquelin, *An. de Ch.* vol. lxxxviii.

Sect. IV.—*Platinum.*

(939.) A. Platinum is first known to have been seen by Mr. Wood, assay-master in Jamaica, in 1741. From him, Dr. Brownrigg received a specimen which was presented to the Royal Society in 1750. In 1748 it was seen by Ulloa, a Spanish Mathematician, who accompanied the French Academicians, in 1735, to Peru, for the purpose of measuring a degree of the meridian. Experiments on it were published by Wood, in 1750, (*a.*) and by Lewis, in 1754. (*b.*) Other dissertations on it may be found from the references to this section. (*c.*) The first Platinum known was from Choco and Santa Fé, in South America. Vauquelin detected it among some silver-ores from Estramadura; it has subsequently been brought from St. Domingo, and from the gold-mines of Brazil. Still more recently it has been found in the Province of Antioquia, in North America; and abundantly in the Ural mountains. (*d.*) Its name is derived from the Spanish as a diminutive from *plata*, silver; hence *platina*, and its Latin *Platinum.*

This substance is found in the metallic state either nearly pure, or alloyed with iron, copper, lead, gold, silver, palladium, rhodium, iridium, and osmium.

(940.) B. The grains of crude Platinum are to be dissolved in concentrated nitro-muriatic Acid, with as little heat as possible. Decant off the solution from a black precipitate which remains. A solution of sal ammoniac dropped into the solution, throws down a yellow precipitate; which is to be washed, dried, and gradually raised to a red heat in a porcelain-crucible. Pure Platinum remains in a pulverulent state, and may, by heat and mechanical compression, be reduced to an ingot. (*d.*)

(941.) C. Pure Platinum is less white than silver; and has inferior lustre. It is the heaviest Metal known, having a Specific Gravity = 21, or 22. It is soft, malleable, ductile, and of very difficult fusibility; and a comparatively slow conductor of heat. Has the property of welding.

(942.) D. Platinum is not oxidized by exposure to heat and air. Its oxides are obtained by precipitation from saline solutions. Three oxides are described by Chemists, but the first is not quite well ascertained.

(943.) E. Nitro-muriatic Acid is the best solvent of Platinum; but it is also acted upon by pure Chlorine. The point is not fully ascertained, but it seems probable that there are three chlorides of Platinum.

(944.) F. Unknown.

(945.) G. Unexamined.

(946.) H. Sulphuret of Platinum has been formed, but it seems to be a compound not possessed of great stability. (*e.*) The phosphuret is a bluish-grey powder not fusible. The seleniuret is described by Berzelius.

(947.) I. On the whole, Platinum may be considered as well disposed to form alloys with the other Metals; and, in some instances, the combination is effected with great violence.

(948.) K. Platinum is not acted upon by any Acid except the nitro-muriatic; but its oxides form numerous Salts with other Acids by indirect processes. The alkalis, also, aided by heat, have some action upon it; hence a caution arises with regard to the use of Platinum-crucibles in analysis.

(949.) L. Solutions of the Salts of Platinum have a yellowish or reddish-brown colour. They are not precipitated by infusion of galls, or by prussiate of potassa. Pure ammonia, or potassa, throw down small orange-coloured crystals. Hydrosulphuric Acid throws down a black, pulverulent precipitate.

(950.) M. The very difficult fusibility of Platinum renders it a valuable Metal, in forming apparatus for many purposes of Chemical research. Being harder and less fusible than gold, it is now used for the touch-holes of guns; perhaps, also, it unites better with the iron of the barrel.

References to § 4.

(*a.*) *Phil. Trans.* vol. xliv. (*b.*) *Phil. Trans.* vol. xlviii. and l. (*c.*) Lewis, *Com. Phil. Techn.* p. 443; Margraaf, *Opusc.* vol. ii. p. 226; Macquer and Beaume, *Mém. Par. Acad.* 1758, p. 119; Buffon, &c. *Jour. de Ph.* vol. iii. p. 234; Bergman, *Opusc.* vol. ii. p. 166; Lavoisier, *An. de Ch.* vol. v. p. 137; Moussin Poushkin, *An. de Ch.* vol. xxiv. p. 205; Morveau, *An. de Ch.* vol. xxv. p. 3; Berzelius, *An. de Ch.* vol. lxxxiii.; E. Davy, *Phil. Mag.* vol. xl. pp. 27, 209, 263, 350. (*d.*) Wollaston, *Phil. Trans.* 1827. (*e.*) Vauquelin, *An. de Ch. et de Ph.* vol. v. p. 263.

Sect. V.—*Gold.*

(951.) A. This beautiful and valuable Metal has been known from the earliest times; a circumstance easily explained when we remember that it usually occurs in the native metallic state. From one other ore only is it obtained in any considerable quantity, in which it is combined with tellurium. Native Gold is found principally in filaments traversing primitive rocks, in the beds of rivers, in grains washed out from similar mountains, or in alluvial soils.

(952.) B. When the grains of Metal are sufficiently large to be visible, they are picked out and purified by fusion and cupellation. But when the grains are very minute, and mingled with sand, or it is necessary to pulverize the rocky matrix containing the Metal, it is usual to complete the process by amalgamation. The sand, or powder, is first washed with water in such a way as to allow the heavier particles of Gold to remain in the vessel; this auriferous sand is then agitated with mercury, by which the Gold is taken up and the silicious matter remains. The mercury is then distilled off from the Gold, and subsequent cupellation is employed to remove any impurity arising from the baser Metals. Should silver also be present, the assayer's operation of parting is resorted to to obtain absolute purity.

(953.) C. Various shades of yellow describe the colour of Gold; and it is singular that, without affecting any of its other properties, if a small quantity of borax be added to Gold in fusion, the colour becomes very pale, whilst nitre has the contrary property of rendering it very high-coloured. It is capable of a high polish from the burnisher. Its Specific Gravity is about 19.3, being higher than any other Metal, platina excepted. It is the most ductile and malleable of metals. "It may be beaten out into leaves so thin, that one grain of Gold will cover 56¾ square inches. These leaves are only 1-282000 of an inch thick. But the Gold leaf with which silver wire is covered, has only 1-12 of that thickness. An ounce of Gold upon silver wire is capable of being extended more than 1300 miles in length." (Thomson.)

Great as is the density of Gold, if one of these leaves be carefully spread between two plates of glass, it will be found to transmit the green rays of light; and it is singular that the same colour is developed on the surface of a mass of Gold in a state of fusion.

In tenacity, Gold is inferior to iron, copper, platinum, and silver. Its fusing point may roughly be stated at 1300° Fahrenheit. In all furnace heats it may be considered as absolutely fixed; but by the heat of Tschirnhau's lens, the discharge of an Electrical battery, or the Gas-blowpipe, it may be volatilized. The fumes raised by the first of these processes were seen by Macquer to gild a plate of silver placed five or six inches above it.

(954.) C. Exposed to atmospheric air, to oxygen, or to water, Gold undergoes no alteration, but aided by the heat of a powerful lens, or by an Electric discharge, its oxide may be formed though in very minute quantities. By the heat of the Voltaic pile, or the Gas-blowpipe, leaves or small wires of Gold undergo rapid combustion, and an oxide is produced. It is the general opinion of Chemists that there are at least two oxides of Gold. If a solution of Gold in nitro-muriatic Acid be evaporated just to dryness, and redissolved in water, and to this neutral solution caustic potash be added, and the whole exposed to heat, an abundant precipitate is produced. This is to be carefully washed with water, and dried, but without artificial heat. Thus is formed a reddish-brown powder, the tritoxide of Gold; which by a very moderate heat again parts with its oxygen, and returns to the metallic state.

If instead of evaporating only to dryness the trithydrochlorate formed in the above experiment, the heat is continued as long as any Acid Gas is evolved, a straw-coloured mass remains insoluble in cold water, which is a prot-hydrochlorate of Gold; and from this a green-coloured protoxide may be separated by digestion in caustic potassa. This combination does not, however, possess great permanency, for one-third of it passes to the state of tritoxide at the expense of the other two-thirds, which return to the metallic state. Clearly, then, the tritoxide contains thrice as much oxygen as the protoxide, and Berzelius has strong ground for his suspicion that an intermediate oxide exists.

(955.) E. When Gold in a state of minute division is heated in chlorine, a yellow chloride is formed, which by the addition of water passes into a hydrochlorate, as is usual in such cases.

(956.) F. Unknown.

(957.) G. Hydriodate of potash produces in a solution of muriate of Gold, a brownish-yellow precipitate, insoluble in cold water, and decomposable by heat.

(958.) H. Gold does not unite with azote, hydrogen, carbon, boron, or silicon. Pelletier formed the phosphuret by dropping small pieces of phosphorus into Gold in fusion, and Oberkampf by precipitating hydrochlorate of Gold, by water impregnated with phosphuretted hydrogen Gas. Its affinity for sulphur is very slight, but when an alkaline hydrosulphuret is dropped into a solution of Gold, the black metallic sulphuret is precipitated.

(959.) I. As far as hitherto known, Gold appears to unite with every Metal, undergoing such change of properties, as to present a wide field of research. Most ably and laboriously has this inquiry been prosecuted by Mr. Hatchett. (*b*.) All Metals, except silver, copper, and platinum, seem materially to injure its ductility and colour. Lead, bismuth, and antimony, in very small proportions, render it brittle.

(960.) K. Solution of chlorine and the nitro-muriatic Acid are the only decided solvents of Gold; two parts of muriatic to one of nitric Acid form the usual proportions, but three of the former to one of the latter is considered still more effective.

Concentrated nitric Acid dissolves the oxide, and thus a pernitrate is obtained; but the combination is so slight, that either heat or dilution again throws down the metallic oxide.

In a similar manner the tritosulphate is obtained. The hydrochlorate has been before described. Further researches on the Salts of Gold are wanted.

Pelletier states that oxide of Gold is soluble in hydrate of potassa; and in this combination he considers that it acts the part of an Acid. It would also appear that in the process given above for obtaining the tritoxide of Gold, a portion of the Metal remains in solution in the state of a double hydrochlorate of potassa and Gold of high solubility.

(961.) If to a solution of hydrochlorate of Gold diluted with thrice its weight of water, ammonia be added so long as there is any precipitate, but without adding excess, the reddish-yellow precipitate, when washed in water and dried by exposure to air, is Fulminating Gold, a preparation long known to Chemists. By the slightest heat, by percussion, or by friction, it explodes with violence. The temperature necessary to produce this effect has been estimated by Bergman between 120° and 300°. The powder appears to be a true ammoniuret of Gold; and on its detonation, according to Bergman, the following changes take place. The oxygen of the oxide attracts the hydrogen of the ammonia, and watery vapour is produced; the nitrogen also is liberated; and to the elasticity of these two Gaseous bodies, increased by the temperature, the violent effects are attributable. See FULMINATING POWDERS in our *Miscellaneous Division*.

(962.) L. In the solutions of the Salts of Gold, prussiate of potassa produces a yellowish-white precipitate. Infusion of galls gives to the solution a greenish hue, and precipitates the Gold in the metallic state. Hydrochlorate of tin, or a plate of metallic tin, produces a purple precipitate. Proto-sulphate of iron throws down metallic Gold, and from the powder thus produced, the most pure metallic Gold may be obtained. The rationale of this precipitation is simple and beautiful; the protoxide of iron has a strong affinity for more oxygen, and the Gold having only a very weak one, the former is oxidated at the expense of the latter, which being no longer soluble, falls down in the metallic state. Copper, iron, and zinc also precipitate Gold in the metallic state, and several other Metals in the state of a purple oxide.

(963.) M. Perhaps the most important among the uses of Gold is that of coinage: its great ductility fits it for receiving a sharp and beautiful impression from the die, while its scarcity gives to it a convenient value with reference to the other Metals of coinage. Pure Gold is not so well adapted to this purpose as those alloys which possess sufficient hardness to resist the wear to which all coin is subject. The standard or sterling Gold of England consists of twenty-two parts (carats) of pure Gold to two parts of alloy. The alloy consists of silver or copper, or both, according to the colour which is required; the latter Metal having a great tendency to heighten the colour of Gold. It would appear from Mr. Hatchett's experiments that the alloy used in our Gold coinage is the best possible for the purpose, as it resisted ordinary friction better than any other tried. The stamped Gold for watch-cases, &c. is of eighteen carats, for it contains one-fourth alloy; but compounds exist under the name of *Jeweller's Gold*, of every possible degree of deterioration.

One species of gilding upon Metal is performed by uniting Gold to the Metal at a gentle heat, and by the friction and pressure of the burnisher, but *æthereal gilding*, as it is called, is performed upon steel, by mixing a saturated solution of muriate of Gold with three times its weight of sulphuric æther; æther dissolves the oxide of Gold, and the Acid, or a great part of it, subsides. If polished steel be then dipped in the æthereal solution, and immediately immersed in water, it is found to have received a delicate coating of metallic Gold on its surface. (Stodart.) For colouring glass and porcelain, the beautiful, purple precipitate produced by adding protomuriate of tin to a solution of Gold, has long been known under the name of the *Purple powder of Cassius*, the real nature of which still remains rather uncertain among Chemists.

Greatly as the Alchemists boasted of its virtues, Gold had fallen entirely into disuse as a medicine, until very lately; but it now seems to be likely again to have a place in the Materia Medica.

References to § 5.

(*a.*) Lewis, *Commercium, Phil. Techn.* fol. 1763; Proust, *Jour. de Phys.* vol. lxii. or Nich. *Jour.* vol. xiv.; Vauquelin, *An. de Ch.* vol. lxxvii.; Oberkampf, *An. de Ch.* vol. lxxx.; Berzelius, *An. de Ch.* vol. lxxxiii.; Hatchet, *Phil. Trans.* 1803; Hellot, *Mém. Acad. Par.* 1735; Tillet, *Mém. de l'Acad. Par.* 1735; Figuier, *An. de Ch. et de Ph.* vol. ii.; Bergman, *Opusc.*; Stodart on Gilding by Æther, Nich. *Jour.* vol. xi. (*b.*) *Phil. Trans.* 1803.

Sect. VI.—*Iridium.*

(964.) A. Iridium received its name from its discoverer, Professor Tennant, on account of the varying colours of its solutions. Together with osmium, it forms the black powder, remaining after the digestion and solution of crude platinum in nitro-muriatic Acid. Descotils made the same discovery, and Fourcroy and Vauquelin published a series of experiments on these two bodies. Dr. Wollaston perceived that the flat, foliated, white grains in crude platinum were in fact the native alloy of the two Metals.

(965.) B. The black powder above mentioned is to be mixed with an equal weight of potash in a silver-crucible, and continued in a red heat for some time. From this, water procures an orange-coloured solution. The remaining, undissolved powder is to be digested in hydrochloric Acid, and then again subjected to the action of potash as before; these alternate actions being repeated till all is dissolved. Thus an orange-coloured, alkaline solution is obtained, holding the oxide of osmium, combined with potash, and a deep-red acid solution of oxide of Iridium. By evaporating this latter solution to dryness, and again dissolving in water and evaporating, octahedral crystals of hydrochlorate of Iridium are obtained. From a solution of these, a plate of any Metal, except gold and platinum, will throw down Iridium as a black, metallic powder.

(966.) C. This powder, after the purification of a strong heat, is rather whiter than platinum, but can scarcely be said to have been fused, although Mr. Children's powerful Galvanic battery produced an imperfect agglutination of the particles, and the same has since been effected by Dr. Clarke with the Gas-blowpipe. The experiments of Vauquelin render it probable that, after a perfect fusion, this Metal may be slightly ductile; its Specific Gravity is certainly above 18.6.

(967.) D. The affinity of Iridium for oxygen is extremely slight, but it is probable that it forms more than one oxide. By the addition of an alkali to any acid solution of this Metal, one portion of the oxide is precipitated, and another retained in solution. Descotils procured also a blue, volatilized oxide by exposing the Metal to a strong heat.

(968.) E. F. G. Unknown.

(969.) H. Iridium may be indirectly combined with sulphur. Its action with phosphorus and selenium is not known, and with the other substances of this class its combination is not very probable.

(970.) I. Tennant alloyed it with lead, copper, silver, and gold, but could form no alloy with arsenic. Vauquelin combined it with tin; and like rhodium, it appears to increase the hardness of the Metals with which it is combined.

(971.) K. No single Acid is capable of dissolving Iridium; even the nitro-muriatic is with difficulty made to take up one-three-hundreth of its weight of the Metal.

The sulphate and hydrochlorate of this Metal give green or blue solutions according to their state of dilution; the nitrate, when concentrated, has a red colour. Double Salts of the hydrochloric Acid with the alkalis and oxide of Iridium exist, and are of a deep-purple colour.

(972.) L. From solutions of this Metal almost all Metals produce a precipitate of reduced Iridium, owing to its weak affinity for oxygen. Tincture of galls produces after some time a red precipitate; but according to Tennant the solution of the crystallized hydrochlorate is only rendered colourless by infusion of galls. Prussiate of potassa, hydrochlorate of tin, and carbonate of potassa, without any precipitation being produced. Hydrosulphurets destroy the colour of the solution, but by aid of heat produce a black precipitate.

(973.) M. None.

References to § 6.

Tennant, *Phil. Trans.* 1804; Descotils, *An. de Ch.* vol. xlviii.; Fourcroy and Vauquelin, *An. de Ch.* vol. xlix. and vol. l.; Vauquelin, *Au. de Ch.* vol. lxxix.

PART III.

CHEMISTRY OF ORGANIZED BODIES.

Part III.

(974.) WE have now arrived at a difficult but most interesting and important branch of Chemical Science. There are but two methods for producing a really useful review of the state of knowledge on the subjects to which this Part refers. The one to give a detailed and systematic account of all the researches which have been made on the various Organic substances; and the other merely to recite their names, giving little more than a complete series of references to the original Memoirs for the benefit of those who may wish to enter these fertile fields of discovery. A middle course would offer little real utility. From the former we are prohibited by the space which such a Treatise would occupy in this Work: and we therefore adopt the latter.

By Organic Chemistry we are to understand the examination of the properties, the proximate and ultimate analyses of all substances, immediately seen in, or ultimately to be traced to, the vegetable or animal kingdoms; products obtained from, or educts existing in, organized bodies. Numerous as are the substances referable to this class they are formed from a very few ultimate elements; and can, therefore, differ only in the proportions of these elements, or in the mode of their combination. Oxygen, hydrogen, carbon, and nitrogen are the principal ultimate elements so employed by Nature. With these are united, but in far smaller quantities, some earths and metals, with phosphorus and sulphur. Organic substances, therefore, may generally be resolved into the same ultimate elements; though for the most part in dissimilar proportions, they readily undergo decomposition, a red-heat is at all times sufficient for this purpose, and in numerous cases the decomposition is rapid and spontaneous even at ordinary temperatures. By slight causes the affinities and constitutions of these substances are overturned, and new products result; but in most cases it is impossible to reproduce the original substance by a direct union of its constituent ultimate elements.

The proximate analysis of an Organic substance separates it into its proximate elements; that is, into various substances, acid, alkaline, or otherwise, each of which, though itself a compound body, possesses distinct properties, and a definite constitution of two or more ultimate elements. By the ultimate analysis each of these proximate elements is resolved into its ultimate elementary constituents. If, for instance, a few leaves of wood-sorrel were at once submitted to ultimate analysis, we should obtain carbon, oxygen, hydrogen, potash, and one or two other substances of minor importance, and should learn but little of the constitution of the plant or its juices: but if we proceed more systematically, we shall obtain in the proximate elements an Acid called the oxalic; an alkali, potassa, and a small quantity of residuary matter, producing the colour and substance of a plant; and we learn, that a true Chemical Salt, formed by the Acid and the alkali, constitute the peculiarities of the juices of the plant. We then may proceed to the ultimate analysis of both the potassa and the oxalic Acid, resolving the former into oxygen and a metal; the latter into oxygen, hydrogen, and carbon.

The first efforts at Organic analysis consisted simply of destructive distillation, by which the substance might, indeed, be resolved into its Gaseous elements. Those, however, form new combinations among themselves, and this method is therefore very properly abandoned, except for special purposes.

MM. Gay Lussac and Thenard proposed the application of some substance which should readily afford oxygen when heated with the substance to be analyzed. For this purpose they first employed chlorate of potassa, and subsequently the black oxide of copper. This oxide will, if alone, bear a white-heat without parting with its oxygen; though it readily does so at a much lower temperature if any combustible be present. Hence, if three or four grains of any Organic substance containing hydrogen and carbon be mixed with the oxide of copper in a green glass or metal tube, and then exposed to heat, so disposed as to collect the gaseous products over mercury, carbonic Acid Gas and water will be obtained. The former indicates the quantity of carbon, the latter the quantity of hydrogen. The loss of weight sustained by the oxide should in this case agree with the oxygen employed in producing the water and the carbonic Acid. But if oxygen also had been present in the substance analyzed, this would be indicated by a proportion of oxygenized products greater than that due to the mere loss on the oxide of copper. If nitrogen forms a constituent of the substance analyzed, it will pass over in the Gaseous state, and may be separated from the carbonic Acid by removing the latter by potassa. Such is the outline of this process, but for the numerous minutiæ to be observed, consult the references. (*a.*) Very recently, Dr. Prout has devised a most elegant apparatus and method, which may be seen in the *Philosophical Transactions.* (*b.*) The presence of water in the substance to be examined is to be most carefully avoided; and this is best effected by drying it in an exhausted receiver, at some moderate elevation of temperature, and in presence of some highly absorbent substance, such as sulphuric Acid. A convenient apparatus for this purpose has been devised by Dr. Prout. (*c.*) We owe also to Mr. Cooper (*d.*) and to Dr. Ure some useful suggestions and apparatus in this branch of analysis.

It has been found that some proximate elements, having very distinctive Chemical properties, present on ultimate analysis the very same elements, and in the same proportions. Hence it is inferred that such differences as constitute distinct substances, may arise solely from different modes of combination existing among the ultimate elementary atoms. Of this opinion is Gay Lussac, who considers alcohol, for instance, as consisting of a compound of olefiant Gas with water, whilst Berzelius, on the other hand, considers it only a universal compound of atoms of hydrogen, carbon, and oxygen.

CHAPTER I.

Chemistry of Vegetable Bodies.

(975.) We shall now, for the most part, follow M. Thenard in giving a very brief abstract of Vegetable Chemistry. The following laws he considers to be general, as far as researches at present extend.

1. That when a Vegetable substance does not contain nitrogen, and that when the quantity of its oxygen is to the quantity of its hydrogen in a greater ratio than is due to the constitution of water, the substance is acid, whatever be the quantity of carbon entering into its composition.

2. That when these properties are reversed, the substance *may* still be acid, but that in general it is oily, resinous, alcoholic, or ethereal.

3. That when the oxygen and hydrogen are in just ratio for the formation of water, the substance is analogous to sugar, gum, woody fibre, &c.

4. That when any Vegetable substance contains much hydrogen, it contains at the same time much carbon, and the converse.

5. That many Vegetable substances may be represented, as to their composition, by a certain number of volumes of vapour of carbon, of hydrogen Gas, and of oxygen Gas; or by a certain number of volumes of some of those binary compounds which may be produced between hydrogen, oxygen, and carbon.

6. That no Vegetable substance contains at the same time oxygen enough to transform both its hydrogen and carbon into water and carbonic Acid.

Accordant with these views, M. Thenard treats of Vegetable substances under seven different heads, a division which we can only in part adopt.

Class I. Vegetable proximate elements in which the oxygen is in excess with regard to the hydrogen as to the formation of water.
Division 1. Acids.
Division 2. Alkalis.

Class II. Vegetable proximate elements in which the oxygen is in defect with regard to hydrogen as to the formation of water. Oils, bitumens, alcohol, ethers, &c.

Class III. Vegetable proximate elements in which the oxygen and hydrogen are in just proportion for the formation of water. Sugar, honey, gums, &c.

Class IV. Vegetable colouring principles.

Class V. Vegetable proximate elements not noticed in any of the preceding Classes.

(976.) As a general outline of the properties of these substances, it may be well to bear in mind, that all are either solid or liquid at all ordinary temperatures. Many are volatile *per se*, as for example, alcohol, ether, essential oils; others are readily vaporized in different Gases, such are camphor, benzoic, and oxalic Acid. Others are fixed at all temperatures which do not produce their decomposition.

When submitted to distillation, the former undergo no constitutional change, the second sort are partly volatilized and partly decomposed, and the last are entirely decomposed. From the decomposition of those which do not contain nitrogen, there result water, carbonic Acid, acetic Acid, gaseous oxide of carbon, oil, carbon, and carburetted hydrogen. But those which contain nitrogen, afford in addition ammonia, hydrocyanic Acid, and nitrogen Gas.

By the aid of air and moisture many of these substances undergo spontaneous decomposition. For more complete details of the action of the other simple and compound elements we must refer to the Work of M. Thenard. (*e.*)

(*a.*) Gay Lussac and Thenard, *Rech.* vol. ii.; Prout, *An. Phil.* vol. iv. p. 270; Thenard on Anal. Children's Translation; Prout's *Apparatus*, Henry's *Elements*, vol. ii. p. 182; Bischoff, *An. Phil.* N. S. vol. viii. p. 308. (*b.*) Prout, *Phil. Trans.* 1827, p. 129. (*c.*) *An. Phil.* vol. iv. p. 272. (*d.*) *An. Phil.* N. S. vol. vii. p. 170. (*e.*) *Traité*, vol. iii. p. 576.

CLASS I. DIVISION I.

Vegetable Acids.

(977.) With the greater part of these substances the salifiable bases unite to form Salts. All redden Vegetable blues, and all consist of oxygen, hydrogen, and carbon. M. Thenard enumerates thirty-four which have been mentioned by Chemists, but some are now proved to be identical substances.

Acids that are both natural and artificial.

(978.) *Acetic.* This Acid has been long known; it is most abundantly obtained by the acetous fermentation, or by the destructive distillation of Vegetable bodies, and it is found among the juices of some plants. The impure acetous Acid, now obtained from the distillation of wood, is called pyroligneous Acid, and by subsequent purification becomes a limpid vinegar, or a much stronger Acid according to circumstances. The strongest acetic Acid is obtained by distillation from the acetates, those especially of potassa or copper. Thomson has shown that the only correct estimate of acetic Acid is to be found in its neutralizing power, and that the Specific Gravity cannot be depended upon. This Acid forms numerous and important Salts.

See Mollerat, *An. de Ch.* vol. lxviii.; Colin, *An. de Ch. et Ph.* vol. xii.; Darracq, *An. de Ch.* vol. xli.; Chenevix, *An. de Ch.* vol. lxix.; Berzelius, *An. de Ch. et Ph.* vol. xxvi.; Phillips, *An. Phil.* N. S. vol. i. ii. iv.; Berzelius, *An. Phil.* N. S. vol. viii.

(979.) *Malic Acid* was discovered by Scheele in 1785. It exists in the juice of the apple, and hence its name. Also in the juices of gooseberries, currants, and oranges. In the houseleek, where it is combined with lime. Mr. Donovan discovered in the juice of the fruit of the *Sorbus aucuparia*, an Acid which, not agreeing with the described characters of the malic, he called the sorbic. It seems now proved that the Acids are the same, but that Mr. Donovan's description was accurate, and those previous to his not so, from impurities present in the malic Acids heretofore examined. This Acid forms Salts which are soluble in water and some highly so.

See Donovan, *Phil. Trans.* 1815; Braconnot, *An. de Ch. et Ph.* vol. vi. viii.

(980.) *Oxalic Acid.* This Acid was first recognised by Bergman. It is found in the *Oxalis acetosella*, (wood-sorrel,) in the *Rumex acetosa*, (common sorrel,) and in several lichens. It may be formed abundantly by the action of nitric Acid on sugar. Oxalic ry. Acid seems to have this peculiarity that it contains no hydrogen. It is a most rapid and fatal poison.

See Berzelius, *An. de Ch.* vol. xciv.; Dōbereiner, *An. de Ch. et Ph.* vol. xix.; Gay Lussac and Thenard, *Rech.*; Thomson, *First Principles*, vol. ii.; Wollaston, *Phil. Trans.* 1818.

Acids produced by Nature only.

(981.) *Benzoic Acid.* A substance found in some balsams; in vanilla, castor, in some plants, and in the urine of some herbivorous animals. It is obtained in white, crystalline filaments by sublimation. A few Salts formed by this Acid have been described.

See Fourcroy, *An. de Ch.* vol. lxix.; Berzelius, *An. de Ch.* vol. xciv.

(982.) *Citric Acid.* Scheele first submitted the juice of the lemon to Chemical examination and proved it to contain a distinct Acid. It exists also in small proportion in some other fruits. This Acid crystallizes readily.

Consult Fourcroy, *Système;* Gay Lussac and Thenard, *Recherches;* Berzelius, *An. de Ch.* vol. xciv.

(983.) *Fungic Acid.* M. Braconnot has thus named an Acid found by him in the juice of some of the Fungi.

See *An. de Ch.* vol. lxxxvii. p. 237. 253.

(984.) *Gallic Acid.* This Acid was examined and described by Scheele in 1786. It is found in some astringent barks and in the gall-nut.

See Scheele, *Essays;* Braconnot, *An. de Ch. et Ph.* vol. ix.

(985.) *Ellagic Acid.* Such is the name formed by reversing the word Galle, and applied by M. Braconnot, in 1818, to an Acid first noticed by M. Chevreul in 1815; and supposed to exist in the gall-nut together with the gallic. This Acid is little known.

See *An. de Ch. et Ph.* vol. ix. p. 187.

(986.) *Igasuric Acid.* This substance, so termed by MM. Pelletier and Caventou, was discovered by them in examining the active principles of the bean of St. Ignatius. (*Nux vomica.*) M. Thenard has doubts of the peculiar nature of this Acid.

See Pelletier, *An. de Ch. et Ph.* vol. x. p. 167.

(987.) *Quinic Acid.* This Acid is found in the Quinquina, or Cinchona bark, united with other Vegetable elements. It has a strong, acid flavour, free from all bitterness; does not easily crystallize; forms a class of Salts which have been little studied. See Vauquelin, *An. de Ch.* vol. lix. By English writers this Acid is sometimes spelt Kinic.

(988.) *Laccic Acid.* Such is the name given by M. John to an Acid which he obtained from Stick Lac. It is at present very little known. See Schweiggers, *Journ.*, vol. xv.; or *An. de Ch. et Ph.* vol. i. p. 445; Pearson, *Phil. Trans.* 1794.

(989.) *Meconic Acid.* This Acid was discovered by M. Sertürner, in his valuable researches into the constituent principles of opium. It derives its name from *μήκων*, a poppy. See Sertürner, *An. de Ch. et Ph.* vol. v. p. 21; Robiquet, *An. de Ch. et Ph.* vol. v. p. 280.

(990.) *Mellitic Acid.* Klaproth discovered this Acid combined with alumina in a rare mineral then called Honey-stone from its colour. Consult *An. de Ch.* vol. xxxvi. p. 203, and vol. xliv. p. 232.

(991.) *Moric* or *Moroxylic Acid.* From the juice of the mulberry (*Morus alba*) M. Klaproth, in 1803, obtained this Acid. See *Dict. de Chimie de* Klaproth and Wolff. Thomson, Nich. *Jour.* vol. vii. p. 129.

(992.) *Pectic Acid.* This substance, admitted by M. Thenard into his *System*, was discovered by M. Payen first in the bark of the root of the plant producing Japan varnish. M. Braconnot has continued the inquiry, and found the same substance to exist in all Vegetables. The name is derived from πηκτὶς, a coagulum, from the gelatinous appearance which it always presents. See Payen, *Jour. de Pharmacie*, vol. x. p. 385; and *Jour. de Chim. Médicale*, vol. i. p. 539; Braconnot, *An. de Ch. et Ph.* vol. xxviii. p. 173, and vol. xxx. p. 96. Part III.

(993.) *Acid of the strychnos-pseudo-kina.* A substance very little known, but mentioned by Vauquelin. *Bulletin de la Société Philomatique, Mars*, 1823.

(994.) *Succinic Acid.* This Acid is obtained from amber by gentle distillation. It exists also in some sorts of turpentine, and a few of its Salts have been noticed. See Robiquet and Colin, *An. de Ch. et Ph.* vol. iv. p. 326; *An. Phil.* vol. xv. p. 388; Berzelius, *An. de Ch.* vol. xciv. p. 189.

(995.) *Sulpho-sinapic Acid.* MM. Henry and Garot separated this substance from the fixed oil of mustard. See *Jour. de Chimie Médicale*, No. X. and XI.

(996.) *Tartaric Acid.* After so many Acids, which as yet are scarcely known by name, we arrive at one that has been long noticed. Its presence was recognised in cream of tartar by Du Hamel, Margraaff, and Rouelle the younger; but Scheele first examined it in an uncombined form. Tartaric Acid seems to exist in the juices of several acidulous fruits, and is deposited in combination with lime and potassa in considerable quantity from new wines. The tartrates have excited considerable attention, as some are serviceable in Medicine: such are the tartrate of potassa and soda; (Rochelle Salts;) the bitartrate of potassa; (cream of tartar;) tartrate of antimony and potassa, (tartar emetic.) See Retzius, *Stock. Trans.* 1770; *An. de Ch.* vol. xlvii.; Thenard, *Syst.* vol. iii. p. 677.

Acids produced solely by artificial Processes.

(997.) *Camphoric Acid.* This substance is obtained from camphor by treating it with a large excess of nitric Acid. It was discovered in 1785 by M. Kosegarten. See *An. de Ch.* vol. xxiii. p. 153; vol. xxvii. p. 19; and vol. lxxxiv. p. 301.

(998.) *Mucic Acid.* This Acid was at one time called the saclactic, because obtained by Scheele from sugar of milk in 1780. It is now formed by treating sugar of milk, gum, and some other substances with nitric Acid. See Scheele, *Memoirs;* Langier, *An. de Ch.* vol. lxxii. p. 81; Tromsdorff, *An. de Ch.* vol. lxxi. p. 79; Labillardière, *An. de Ch. et Ph.* vol. ix.; Berzelius, *An. de Ch.* vol. xciv.

(999.) *Nanceic Acid.* So named by its discoverer, M. Braconnot, from Nancy, the place of his residence. It appears to form spontaneously upon the change to acescence in certain Vegetable juices. *An. de Ch.* vol. lxxxvi. p. 84. The experiments of M. Vogel led M. Thenard to suspect this Acid to be identical with the lactic. *Jour. de Pharmacie*, vol. iii. p. 491.

(1000.) *Suberic Acid.* This Acid was discovered by M. Brugnatelli in 1787; it is formed by the action of nitric Acid on Cork. See Brugnatelli, Crell's *Annals*, 1787; Bouillon Lagrange, *An. de Ch.* vol. xxiii.; Chevreul, *An. de Ch.* vol. lxii.; Bussy, *Jour. de Pharm* vol. viii. p. 107.

(1001.) *Pyr-Acids.* There is a class of Acids produced by the distillation of certain other Vegetable Acids. The names of those described are the Pyrocitric, Pyromalic, Pyromucic, and Pyro-tartaric. See Thenard, *Syst.* vol. iii. p. 706.

DIVISION II.

Vegetable Alkalis.

(1002.) The outline which we are about to give of the general properties of these substances is extracted from M. Thenard's *System.* The discovery of this class of bodies originated with M. Sertürner during his excellent analysis of opium, made in 1805. A subsequent Memoir, however, which he published in 1815, was the first to call the attention of Chemists effectually to the point.

The Vegetable Alkalis best known are morphia, strychnia, brucia, cinchonia, quinina, veratria, delphia, and emetia.

Picrotoxia, solania, caffeina, and atrophia seem to belong to the same class, but have been less studied.

Daphnia, hyoscyamia, daturia, aconitina, and cicutina have been announced, but are still less known.

All these Vegetable salifiable bases are solid, white, bitter or acrid, scentless, heavier than water, and change syrup of violet to green. Veratria, delphinia, and emetia can only be obtained in powder, but the rest are capable of crystallization. When decomposed by heat, they all give ammoniacal products among other Gases, in consequence of the nitrogen they contain. All are almost insoluble in water; alcohol being their true solvent. Sulphur does not combine with them. Chlorine and iodine, by aid of water, dissolve them. Their saturating power is feeble. Generally speaking, their sulphates, nitrates, and hydrochlorates are soluble. On the other hand, many neutral tartrates, oxalates, and gallates are insoluble. Excess of Acid always induces solubility. All alkalis, and even magnesia, disengage the Acids from these Vegetable bases; but in their turn these are capable of removing the Acids from most other oxides. In a neutral solution of one of these Vegetable Salts, infusion of galls forms, from the insolubility of the gallate, precipitates, which the Acids or alcohol redissolve.

These Vegetable Alkalis do not exist free in the Vegetables which produce them, but are there united with Acids; and as far as at present known, it is to the presence of these Salts that the active properties of the plants are due.

The general outline of the process by which they are separated is this: the Vegetable juices are boiled with magnesia and water. The precipitate obtained is dried and boiled in pure alcohol; thus a solution of the alkali is obtained, and from this the alcohol may be removed by careful evaporation.

All these alkalis contain oxygen, carbon, hydrogen, and nitrogen. The action of all on the animal economy is very active, and is greatly increased when they are in the state of Salts, from their more ready solubility.

(1003.) *Morphia.* This alkali, discovered by Sertürner, is obtained from opium, and bids fair to form a most valuable addition to Medical Science. For the mode of its preparation see Robiquet, *An. de Ch. et Ph.* vol. v. p. 279; Hottot, *Jour. de Pharm.* vol. x. p. 475. For its medicinal application see Orfila, *Jour. de Chim. Médicale,* vol. i. p. 165, 221; Lassaigne, *An. de Ch. et Ph.* vol. xxv. p. 102; Gairdner, *Med. and Phys. Jour.* vol. xl. p. 276; Bardsley, *Hospital Facts, &c.*

(1004.) *Cinchonia.* Dr. Duncan of Edinburgh first recognised this as a distinct Vegetable principle found in the Cinchona bark, and chiefly in the *Cinchona Condaminea.* Its action seems to be much the same as that of Quinina, but being a rarer substance it is not in such general use. See Majendie, *Formulaire pour la Prèparation et l'Emploi de plusieurs nouveaux Médicamens.*

(1005.) *Quinina.* This alkali was discovered by MM. Pelletier and Caventou in the yellow bark *Cinchona cordifolia.* The sulphate is now very largely employed in Medicine, and its valuable properties are established beyond the reach of doubt. See Pelletier and Caventou, *An. de Ch. et Ph.* vol. xv.; Majendie, *ut suprà*; Elliotson, *Medico-Chirur. Trans.* London, vol. vii. p. 584; Bardsley, *Hospital Facts,* p. 133.

(1006.) *Emetina.* This alkali, discovered by M. Pelletier, is found only in the Ipecacuanha root. It is the active emetic principle of that plant. See Pelletier, *Jour. de Pharm.* vol. iii.; *An. de Ch. et Ph.* vol. xiv. p. 180; Majendie, *ut suprà.*

(1007.) *Strychnia.* This was the first Vegetable alkali discovered by MM. Pelletier and Caventou; it exists in plants of the genus *Strychnos,* one of which is the *Nux vomica* bean. This also promises to form a valuable Medicine, especially in cases of paralysis. See Pelletier and Caventou, *An. de Ch. et Ph.* vol. x. p. 142; Bardsley, *Hospital Facts,* p. 1; Majendie, *ut suprà.*

(1008.) *Brucia.* An alkali obtained from the false Angustura bark, (*Brucæa anti-dysenterica,*) existing also in the bean of St. Ignatius, or *Nux vomica.* See *An. de Ch. et Ph.* vol. xii. p. 113; Bardsley, *ut suprà,* p. 59.

(1009.) *Veratria.* This alkali exists in the seed of the *Veratrum sebadilla,* the root of the white hellebore, *Veratrum album,* and in that of the *Colchicum autumnale.* See *An. de Ch. et Ph.* vol. xiv. p. 75; *Jour. de Ph.* 1821, p. 64; Bardsley, *op. cit.* p. 199.

(1010.) *Delphinia.* This substance has as yet been obtained only from the seeds of the *Delphinium staphisagria.* See Lassaigne and Feneulle, *An. de Ch. et Ph.* vol. xii. p. 358; *Jour. de Phar.* vol. ix. p. 4.

(1011.) *Picrotoxia.* Boullay first recognised this alkali in the berry of the *Menispermum cocculcus.* Its name is derived from its bitter taste and poisonous properties. See *An. de Ch.* vol. lxxx.

(1012.) *Solania.* This substance, as yet little known, was found by M. Desfosses in the berries of the *Solanum nigrum,* and in the substance of the *Solanum dulcamara.* See Desfosses, *Jour. de Phar.* vol. vi. p. 374, and vol. vii. p. 414; Payen and Chevallier, *Jour. de Ch. Méd.* vol. i. p. 517.

(1013.) *Atrophia.* M. Brandes discovered this alkali in the leaves of the *Atropa belladonna.* (Deadly Nightshade.) It seems to be a violent poison, similar in its operation to the decoction of the plant itself. See Brande, *An. Phil.* N. S. vol. i. p. 263; Runge, *An. de Ch. et Ph.* vol. xxvii. p. 32.

The remaining substances of this kind are at present little known; but we commit the subject to the attention of the Chemical reader with an assurance that in it he will find a wide field of interesting research; accompanied by a very reasonable expectation of arriving at results of the greatest importance to Medical Science.

CLASS II.

Vegetable Proximate Elements, in which the Oxygen is in defect with regard to the Hydrogen, as to the formation of water.

These substances are in general oily, resinous, alcoholic, or ethereal; some among them possess acid properties. All are very rich in carbon, this substance sometimes amounting to four-fifths of their weight. They are in general fusible, and very combustible. Many may be volatilized by heat, unchanged; others are decomposed. Almost all are very soluble in spirits of wine, and insoluble, or very slightly so, in water.

(1014.) *Stearine and Elaine.* It appears from the researches of M. Chevreul that all fats and fixed oils contain two distinct principles to which he has applied these names. The former gives consistency, the latter, of a more liquid nature, produces fluidity. In the formation of soaps these principles are completely changed into three others, Margaric Acid, Oleic Acid, and Glycerine See Chevreul *sur les Corps Gras.*

(1015.) *Fixed Oils.* These are for the most part liquid at our ordinary warmer temperatures. Yellow is the prevailing colour, and all are lighter than water. Of this class, olive oil, castor oil, nut oil, linseed oil, &c. will readily occur to the reader. For analyses of oils, see Gay Lussac and Thenard, *Recherches;* Saussure, *An. de Ch. et Ph.* vol. xiii. p. 351; Braconnot, *An. de Ch.* vol. xciii. p. 225. On the nature and formation of soaps, see Thenard, *Syst.* vol. iv. p. 70; D'Arcet, &c. *An. de Ch.* vol. xix. p. 253; Colin, *An. de Ch. et Ph.* vol. iii. p. 5; Marcel de Serres, *An. de Ch.* vol. lxxvi. p. 54; Chevreul *sur les Corps Gras.*

(1016.) *Essential Oils.* These oils, sometimes termed essences, contain the odoriferous properties of various plants, and hence they form, either alone, or as spirituous solutions, the basis of most perfumes. In many properties they differ from the fixed oils. They are acrid, caustic, very fluid, highly volatile, and readily combustible on the approach of burning bodies. Partially soluble in water, not capable of forming very intimate combinations with alkalis. Those most generally known are obtained from the lemon, bergamot orange, lavender, rosemary, aniseed, rose, jasmin, caraway seed, ambergris, and turpentine from the resin of the pine.

(1017.) *Resins.* These substances are generally solid, brittle, but little heavier than water, scentless and tasteless when pure, generally of a yellow or brown colour; non-conductors of electricity, but themselves readily electric by friction. Combustible in the open air with much flame and black smoke, which, when collected, condenses into the well-known substance lamp-black. The substances in this class are common resin, colophony, pitch, balsam of copiaba, copal, elemi, mastic, sandarach, dragon's blood, some viscid turpentines, Burgundy pitch, and a few others. For analyses of these bodies, see Gay Lussac and Thenard, *Recherches*, and some curious experiments by Mr. Hatchett, *Phil. Trans.* vol. xciv., xcv., xcvi.

(1018.) *Gum Resins.* These substances are exudations from the bark and branches of trees; they are much used in Medicine and in the Arts. In this class are assafœtida, gum ammoniac, galbanum, olibanum, myrrh, opoponax, scammony, aloes, lac, and a few others. For the Natural History of these bodies, consult any good *Pharmacopœia.*

(1019.) *Balsams.* These, like the last mentioned, are in fact compound bodies, and for the most part consist of resin, benzoic Acid, with some oil peculiar to each. For examples we may name balsam of Peru, balsam of Tolu, benzoin, and storax.

(1020.) *Caoutchouc.* This useful and curious substance is the inspissated juice of three or four East Indian and American plants.

(1021.) *Wax.* Many plants seem to elaborate this substance by vessels proper for its production and deposition; it exists in the pollen of plants, and hence is collected in large quantities by bees. A question has arisen whether these animals only collect wax, or have the power of secreting it: the latter is the opinion of Mr. Huber.

(1022.) *Camphor.* This substance exists in various species of the genus *Laurus*, but is principally obtained in Japan from the *Laurus camphora.* It is subsequently refined in Europe by sublimation. See Clemandot, *Jour. de Pharmacie,* vol. iii. p. 323; *An. de Ch.* vol. xxi., xxxvii., xl., xlviii.; *An. de Ch. et Ph.* vol. iv. p. 310, and vol. viii. p. 78; Chevreul, *An. de Ch.* vol. lxxiii. p. 167.

(1023.) *Alcohol.* This substance well known in an impure state as spirits of wine, is then combined with water from which it is by no means easy to effect a separation. Alcohol is a product formed during the vinous fermentation: hence it exists in wine, beer, &c. To this substance these Liquids owe their intoxicating properties. The Specific Gravity of the purest alcohol, supposed anhydrous, is 0.796 at 60° Fahrenheit. When its Specific Gravity is 0.820, it boils at 176° Fahrenheit, and is highly inflammable. It is not clear that alcohol has never been frozen: Mr. Walker found it fluid at – 91° Fahrenheit. Alcohol dissolves potassa, soda, lithia, ammonia, and the vegetable alkalis, but does not act on the earths, or metallic oxides. Whether alcohol existed in wines as such, or was formed during their distillation, was long doubted; but the question was at length decided in the affirmative by some good experiments of Mr. Brande. On the modes of obtaining pure Alcohol see Gay Lussac, *An. de Ch.* vol. lxxxvi. A curious fact is mentioned in the *Journal of Science*, vol. xviii., *viz.* that if impure alcohol, contained in an ox's bladder, be suspended in the air, the water escapes, and the alcohol becomes concentrated. On the constitution of alcohol, see Saussure, jun. *An. de Ch.* vol. lxxxix. For strength of alcohol, see Table IX.

(1024.) *Æthers.* M. Thenard divides æthers into three classes: 1. those which consist of hydrogen, carbon, and oxygen; and are formed by the mutual action of certain Acids, alcohol, and water; 2. those which result from the combination of bicarburetted hydrogen with some Acid employed in their formation; and 3. those which consist of a direct union of alcohol with the Acid employed for their formation.

Of the first kind are sulphuric, phosphoric, arsenic, and fluo-boric. Of the second kind are hydrochloric, hydriodic, and hydro-fluoric. And of the third, nitric, and several produced by vegetable Acids.

As an example of this sort of substance, take sulphuric æther. Sulphuric Acid is added to an equal quantity of alcohol in a glass flask, but with great caution agitating it on each addition of Acid. A gentle heat is then applied, and the æther distils over, and is condensed in a cool receiver. Sulphuric æther has a pungent, and to most persons an agreeable odour. Its

Specific Gravity is about 0.7, and it is highly volatile. Consult Thenard, *Système*, vol. iv. p. 146; *Mém. d'Arcueil*, vol. i. ii.

(1025.) *Bitumens, Coal, Amber, &c.* It would require volumes to do justice to the Natural History of this important class of substances, which we must dismiss after a few lines of description. All are generally believed to be the results of the spontaneous decomposition of Vegetable matters, though the period at which they must have flourished is, in many cases, very remote. Bitumens proper, and naphtha, a more limpid and volatile bitumen, (containing no oxygen,) are generally found as exudations from the earth in parts subject to the operation of volcanic fires. Coal is found in extensive deposits in several parts of the earth, and forms by far the richest mineral treasure of England. Amber is found in masses, chiefly on the Northern European shores; and on the coast of Sicily, near the mouth of the Giaretta. Retinasphalt, first described by Mr. Hatchett in the *Phil. Trans.* for 1804, is found in small quantity with brown coal at Bovey, in Devonshire.

CLASS III.

Vegetable Proximate Elements in which the Oxygen and Hydrogen are in just proportion for the formation of water.

All substances in this class are solid, heavier than water, scentless, and have no action on Vegetable colours. They are not volatile, but are altogether decomposed by heat. When placed in contact with 100 or 150 times their volume of chlorine, they become carbonized in a few days, and the chlorine passes to the state of hydrochlöric Acid Gas.

(1026.) *Sugar.* Of this substance four kinds at least are recognised by Chemists: that of the cane, beet-root, and other such Vegetables; of the grape, and other fruits; of some of the Fungi; and that which is found in the urine of persons labouring under one variety of *Diabetes.*

(1027.) *Honey* is a substance greatly analogous to sugar in its nature, secreted by some plants, and collected by bees. It has been questioned how far the process performed by this interesting animal is secretive or merely a process of mechanical separation. On this point see Huber, *Jour. de Phys.* 1804.

(1028.) *Mannite.* This name is given by M. Thenard to the saccharine principle of manna, an exudation from some species of ash.

(1029.) *Asparagine.* The vegetable principle peculiar to asparagus; discovered by MM. Vauquelin and Robiquet. See *An. de Ch.* vol. lvii. p. 88.

(1030.) *Starch.* This name is applied generally to a substance found in a great number of roots and grains; and forming a very considerable share of their nutritive substance. Consult Saussure, *An. Phil.* vol. vi. and *An. de Ch. et Ph.* vol. xi.; Caventou, *An. de Ch. et Ph.* vol. xxxi.

(1031.) *Gum.* This useful proximate element is obtained as an exudation from several plants. The most plentiful variety is from the *Mimosa* genus, growing in hot Countries, and well known as Gum Arabic. The gum of the plum and cherry tree, and even the mucilage obtained by macerating linseed, are believed to be varieties of the same substance. See Bostock, Nich. *Jour.* vol. xviii.

(1032.) *Lignin*, or *Woody Fibre.* The main solid constituent of all trees and plants. See Braconnot, *An. de Ch. et Ph.* vol. xii.

CLASS IV.

Vegetable Colouring Principles.

The substances in this class are found in various parts of Vegetables; and as they are of great importance in the Arts, they have formed the subject of numerous experiments by the most expert Chemists.

(1033.) *Hæmatine.* The colouring principle of logwood, described by M. Chevreul, *An. de Ch.* vol. lxxxi. p. 128.

(1034.) *Carthamine.* Such might serve for the name of a deep-red colouring matter obtained from the *Carthamus tinctorius*, but which has as yet been little examined.

(1035.) *Indigo.* This most valuable and curious Vegetable product is obtained chiefly from a genus of plants produced in Asia and America, and also of inferior quality from the *Isatis tinctoria*, which has long been cultivated in Europe. See Chevreul, *An. de Ch.* vol. lxvi. p. 29; also *Ib.* vol. lxxii. and lxxviii.

(1036.) *Polychroite.* Such is the name given by MM. Bouillon Lagrange and Vauquelin to the colouring principle of saffron, in consequence of the great variety of tints which it is capable of assuming. (πολὺς, many, χρόα, colour.) See their Memoir, *An. de Ch. et Ph.* vol. lxxx. and that of M. Henri, *Jour. de Phar.* vol. vii.

(1037.) *Carmine.* This beautiful pigment is formed from the colouring principle of cochineal with alumina or oxide of tin for a base. Cochineal is obtained from an insect which feeds on the leaves of several species of *Cactus.* See Pelletier and Caventou, *Jour. de Phar.* vol. iv.

Other red dyes are obtained from madder, Brazil wood, &c. The principal yellow dyes, are *Reseda luteola*; quercitron bark; fustic; turmeric; fernambouc, &c. &c.

Upon a knowledge of these substances the Art of Dyeing depends. See Chaptal, *Chimie appliquée aux Arts*; Bancroft, *on Permanent Colours*; Berthollet, *Elémens de l'Art de la Teinture*; Henry, *Manch. Mem.* vol. iii.; and Thenard and Roard, *An. de Ch.* vol. lxxiv.

CLASS V.

Vegetable Proximate Elements not noticed in any of the preceding Classes.

Many substances which will be, or might be, here mentioned, will, most probably, upon further investigation, require to be placed in some one of the preceding classes; but this is an intricate department of the Science, and in it there have been but few zealous labourers.

(1038.) *Gluten.* This substance is sometimes termed vegeto-animal, from partaking of the nature and properties of animal matter. It is a tough, elastic substance, most readily obtained by washing away the fæcula, mucilage, &c. from paste made of any kind of corn. M. Taddei has recently stated gluten to consist of two distinct principles, *gliadine*, soluble in alcohol, and *zymome*, which has not that property. *An. Phil.* vol. xv.

(1039.) *Yeast.* The peculiar principle of this substance is called by some writers *Ferment.* Its distinctive property is that of exciting fermentation in Vegetable matter under certain conditions.

(1040.) *Tannin.* This curious and important body the least subject to this process, and some are not liable to it in any degree. By the Putrefactive Fermentation most disagreeable effluvia are produced, and the substances are resolved into carburetted hydrogen Gases; carbonic Acid; ammonia, if nitrogen be present; water; acetic Acid in some cases; and solid carbonaceous matter.

CHAPTER II.

Chemistry of Animal Bodies.

The substances which we shall enumerate in this Chapter consist of oxygen, hydrogen, carbon, and nitrogen, as their chief elements; but small portions of other substances are united with these, so as to produce important modifications in their general properties. The first three of our classes will consist of simple proximate elements; while the last class will contain those complex Fluids or Solids, which are distinctly recognised as ministering to the functions of animal life.

CLASS I.

Substances neither acid nor oleaginous.

These bodies are altogether decomposed by destructive distillation, and produce water, carbonic Acid Gas, carbonate of ammonia, compounds of cyanic Acid, with ammonia in very minute quantities, Gaseous oxide of carbon, a fetid, animal oil, carburetted hydrogen Gas, nitrogen, and charcoal of a very dense texture. All are decomposable by nitric Acid.

(1065.) *Fibrin.* This is the main substance of muscular fibre, and it exists abundantly in blood and in the chyle. It is a white, solid, tasteless substance. See Chevreul, *An. de Ch. et Ph.* vol. xix.; Gay Lussac, *An. de Ch. et Ph.* vol. iv.; Berzelius, *An. de Ch.* vol. lxxxviii; Braconnot, *An. de Ch. et Ph.* vol. xiii.

(1066.) *Albumen.* This body is found in most animal Fluids and Solids; and almost pure in the white of the egg. Its most marked property is the power of coagulation by heat. See Chevreul, *An. de Ch. et Ph.* vol. xix.; Brande, *Phil. Trans.* 1809; Lassaigne, *An. de Ch. et Ph.* vol. xx.; Bostock, *Medico-Chir. Trans.* vol. ii.

(1067.) *Gelatine.* A substance readily soluble in water, and which forms a portion of most of the harder parts of animals. Glue is gelatine obtained by boiling the skins and hoofs of animals. Isinglass, a more pure or delicate sort, is obtained from the stomachs of certain fishes. Tannin has a strong affinity for it, and thus precipitates a solid compound of the two elements. See Gay Lussac and Thenard, *Rech.* vol. ii. p. 336.

(1068.) *Caseous Matter.* A substance existing in milk, and separated for the making of cheese. See Proust, *An. de Ch. et Ph.* vol. x. p. 29.

(1069.) *Urea.* A singular crystalline Solid which forms a very important ingredient of urine. See Prout, *Medico-Chir. Trans.* vol. viii. p. 529; Vauquelin, *An. de Ch.* vol. xxxii. p. 80.

(1070.) *Picromel.* A substance found in the bile. See Thenard, *Mém. d'Arcueil*, vol. i.; Berzelius, *Medico-Chir. Trans.* vol. iii.; Tiedemann and Gmelin.

(1071.) *Sugar of Milk.* This seems to be of the same nature with the sugar already mentioned (1026.) as occurring in the urine of diabetic patients. See Vauquelin, *Bulletin de Pharmacie*, vol. iii. p. 49; Vogel, *An. de Ch.* vol. lxxii. p. 156; Gay Lussac and Thenard, *Rech.*

CLASS II.

Animal Acids.

Among Animal matters Thenard names twenty-six Acids; nine differing altogether from fatty bodies; ten very considerably allied to them in Nature; three totally differing in origin and constitution; whilst some others are common to the Animal and Vegetable, or to the Animal and Mineral kingdoms.

Acids more or less oxygenated, and differing considerably from fatty Bodies.

(1072.) *Uric*, or *Lithic Acid.* This peculiar Acid was discovered by Scheele, in 1776; it exists with numerous other substances in the urine of many of the higher animals. See Henry, *Manch. Mem.* N. S. vol. ii.; Prout, *Medico-Chir. Trans.* vol. ix.

(1073.) *Pyro-uric Acid.* If uric Acid be exposed to heat in a retort, this Acid is formed and volatilized. See Chevallier and Lassaigne, *An. de Ch. et Ph.* vol. xiii. p. 155.

(1074.) *Purpuric Acid.* This Acid was first recognised by Dr. Prout, and has exercised the ingenuity of some of the best Chemists, but at present it is not well understood. It is obtained by digesting pure uric Acid in diluted nitric Acid. See Prout, *Phil. Trans.* 1818; Vauquelin, *Mém. du Mus. d'Hist. Nat.* vol. vii. p. 253, and vol. ix. p. 155; Brugnatelli, *An. de Ch. et Ph.* vol. viii. p. 201; Lassaigne, *An. de Ch. et Ph.* vol. xxii. p. 334.

(1075.) *Rosacic Acid.* This substance has only been occasionally found in urine. See Proust, *An. de Ch.* vol. xxxvi. p. 258; Vauquelin, *An. de Mus. d'Hist. Nat.* vol. xvii. p. 133; Vogel, *Jour. de Phar.* vol. ii. p. 27.

(1076.) *Amniotic Acid.* This Acid was found by MM. Vauquelin and Buniva in analyzing the amniotic liquor of a cow. See *An. de Ch.* vol. xxxiii. p. 279.

(1077.) *Lactic Acid.* Scheele discovered this Acid in sour whey, in 1780. Berzelius considers it only the acetic disguised by the presence of Animal matter, and the same opinion is maintained by Tiedemann and Gmelin in their important Work on digestion, *Die Verdauung nach Versuche Heidelberg*, 1826.

(1078.) *Formic Acid.* This Acid exists in some species of ants. See Suerson, Gehl. *Jour.* vol. iv. p. 1; Gehlen, *An. de Ch.* vol. lxxxiii. p. 208; Döbereiner, *An. de Ch. et Ph.* vol. xx. p. 329.

(1079.) *Caseic Acid.* M. Proust, who discovered this acid substance, first called it Caseous Oxide, a name which more recent authors have changed to Caseic Acid. Proust, *An. de Ch. et Ph.* vol. x. p. 29.

(1080.) *Cyanic Acid.* We have already mentioned this Acid in another part of this Treatise. (472.)

The following Acids contain little Oxygen, and approach to fatty Substances in their Constitution and Properties.

(1081.) *Sebacic Acid.* This Acid results from the distillation of fatty matters. M. Thenard first recognised it. See *An. de Ch.* vol. xxxix. p. 193.

(1082.) *Cholesteric Acid.* The sebaceous matter contained in the biliary calculi of man was termed *Cholesterine* by M. Chevreul. By treating this substance with nitric Acid, MM. Pelletier and Caventou obtained a peculiar Acid, and gave to it the name of Cholesteric Acid. See *Jour. de Phar.* vol. iii. p. 292.

(1083.) *Stearic Acid.* M. Chevreul, the discoverer, so named this Acid from *στέαρ*, fat. He considers the formation of this Acid, and its union with an alkali, the essential process in the formation of soap. See Chevreul *sur les Corps Gras.*

(1084.) *Margaric Acid.* Discovered also by M. Chevreul, and named, from its pearly appearance, from *μαργαρίτης*, a pearl. This Acid exists in the fat of animals. See Chevreul, *op. cit.*

(1085.) *Oleic Acid.* Another of M. Chevreul's Acids, forming part of the same fatty matters, and capable, like the others, of saturating alkaline bases.

(1086.) *Phocenic Acid.* An Acid obtained by M. Chevreul, by acting on a peculiar oil with alkalis. This oil, called Phocenine, he obtained from the oil of the porpoise. (*Delphinus phocæna.*)

The *Butyric, Caproic, Capric*, and *Hircic Acids* have similar animal origin, and may be found in the Work of Chevreul. An Acid, called the *Cevadic*, is described by Pelletier and Caventou, *An. de Ch. et Ph.* vol. xiv. p. 71.

CLASS III.

Oleaginous Animal Substances.

The substances referable to this class have the following general properties. They become liquid at very slight elevations of temperature; are insipid; very inflammable; insoluble in water; produce by distillation a small carbonaceous residuum, with much fetid oil; but by being passed in a state of vapour through a heated, porcelain tube, they deposit much carbon and evolve carburetted hydrogen Gas: they do not contain azote, and but little oxygen. M. Berard obtained a substance very similar in general properties, by transmitting a mixture of one volume of carbonic Acid, ten volumes of carburetted hydrogen, and twenty volumes of hydrogen through a red-hot tube. Döbereiner produced a similar effect from a mixture of coal Gas and aqueous vapour.

(1087.) M. Thenard says, that before the researches of M. Chevreul the notions formed relative to the fatty bodies were altogether inaccurate. "The fats were considered similar to the fixed oils, in being all as different from each other as they could be; that is to say, as much so as the various species of sugar. M. Chevreul has demonstrated that they are composed of a certain number of ultimate elements, and that the greater part differ from each other only by the relative proportions in which these exist. Of these he distinguishes eight species, to which he gives the following names: *Stearine, Oleine, Cetine, Colesterine, Ethal, Phoceine, Butyrine*, and *Hircine.*

"These are divisible into four well-marked groups.

"The first containing fatty substances which are not altered by alkalis, and are not capable of uniting together, *viz.* cholesterine and ethal.

"The second are convertible by alkalis into glycerine and oleic, margaric, or stearic Acid. Stearine of the sheep, stearine of man, and oleine.

"The third contains those which are transformed by alkalis into ethal, and into margaric and oleic Acids. Cetine.

"The fourth comprehends those bodies which the alkalis change into glycerine, into volatile Acids when distilled with water, and into oleic Acid, or oleic and margaric Acids; phoceine, butyrine, hircine."

It is not in our power to enter into the detail of these substances, so that we must refer our readers to the excellent Work of M. Chevreul *sur les Corps Gras.*

CLASS IV.

Complex Animal Substances.

Besides the substances which have fallen under the preceding three Classes, there are certain other proximate elements, which enter more or less into the composition of Animal matters. Such are certain earthy or alkaline phosphates, carbonates, and sulphates; some Vegetable Salts with alkaline or earthy bases; some oxides; and some Salts formed by Animal Acids.

These, however, are inconsiderable in quantity, and are not exactly the bodies to which we turn our attention at this moment. We place in this class those Solids and Fluids which enter into the constitution of living animals. These substances are in general formed of numerous ultimate elements, which may be supposed to exist in groups, forming again proximate elements, by which the constitution of each substance, as blood, bile, &c., may be described.

Secretions subservient to the function of Digestion.

(1088.) *Saliva.* A limpid Fluid, secreted by glands surrounding the mouth, and poured forth in considerable quantities, to be mixed with the aliments during mastication, and conveyed with the food into the stomach. See Berzelius, *An. de Ch.* vol. lxxxviii. p. 123; Lassaigne, *An. de Ch. et Ph.* vol. xix. p. 176.

(1089.) *Pancreatic Juice.* A Liquid secreted by the pancreas, a gland situated in the epigastric region, and conveyed by ducts opening into the duodenum. Immediate use unknown. See Leuret and Lassaigne, *Jour. de Chim. Médicale*, vol. i. p. 549.

(1090.) *Gastric Juice.* A Liquid, supposed to be secreted by the stomach, and unquestionably of great importance to the process of digestion. The solvent power of this Fluid is most remarkable. See Johnson, *Animal Chemistry*, vol. i. p. 180.

(1091.) *Bile.* A bitter, yellow, or greenish Liquid, secreted by the liver, and conveyed by ducts into the duodenum, to be mingled with the aliment which has passed thither from the stomach. See Johnson, *op. cit.*; Thenard, *Mém. d'Arcueil*, vol. i.; and the Work of Tiedemann and Gmelin.

Substances immediately resulting from digested Aliments.

(1092.) *Chyme.* The aliments are conveyed into the stomach, and there converted into a sort of pulpy matter, which is termed Chyme. For greater clearness, this substance is mentioned, though, as must be obvious, it is not a Chemical element of any sort; nor at all definite in its composition. See Marcet, *An. de Ch. et Ph.* vol. ii. p. 50; Prevost and Le Royer, *An. des Sciences Naturelles*, vol. iv. p. 481.

(1093.) *Chyle.* This name is applied to the Liquid absorbed by the lacteal vessels dispersed throughout the small intestines, and from them conveyed into the thoracic duct. Chyle is a white, opaque, milky-looking fluid. See Vauquelin, *An. de Ch.* vol. lxxxi. and vol. xciv.; Brande, *Phil. Trans.* 1812; Prout, *An. Philos.* vol. xiii.; Prevost and Le Royer, *ut sup.*

(1094.) *Blood.* The general appearance of this Fluid must be familiar to all: very numerous have been the researches made upon it by Chemists, especially with reference to its colouring principle. Blood contains water, albumen, fibrin, a coloured Animal substance, a small quantity of fatty matter, and some Salts. When recent healthy blood is left at rest, it shortly separates into two portions, the one a transparent, yellowish Liquid called the serum; the other an opaque, reddish or brownish coagulum. The latest researches on this much agitated subject have proved that iron is the colouring principle of the Blood.

See Bostock, *Medico-Chir. Trans.* vol. ii. p. 166; Marcet, *Medico-Chir. Trans.* vol. iii. p. 231; Vauquelin, *An. de Ch. et Ph.* vol. xvi. p. 363; Prevost and Dumas, *An. de Ch. et Ph.* vol. xviii. p. 280, and vol. xxiii. p. 50; Brande, *Phil. Trans.* 1812; Engelhardt, *Edinb. Med. and Surg. Jour. Jan.* 1827; Berzelius, *Animal Chemistry*.

(1095.) *Urine.* This excrementitious Fluid is separated by certain glands, the kidneys, in order to be rejected from the system. This Liquid has been the subject of very numerous researches, in consequence of its important pathological relations. Consult Cruickshank in Rollo, on Diabetes, 2d Ed.; Berzelius, *Animal Chemistry;* Henry, *An. Phil.* vol. i.; Scheele, *Essays;* Vogel, *An. de Ch.* vol. xciii.; Prout, *An. Phil.* vol. xv.; Berzelius, *An. Phil.* vol. ii.; Nicolas, *An. de Ch.* vol. xliv.; Dupuytren and Thenard, *Ibid.* vol. lix.; Fourcroy and Vauquelin, *An. de Ch.* vol. xxxi. xxxii.; Wollaston, *Phil. Trans.* 1797; Berzelius, *An. de Ch.* vol. lxxxix.; Proust, *An. de Ch. et Ph.* vol. xiv.; Prout, *On the Nature and Treatment of Calculous Disorders.*

(1096.) *Intestinal Gases.* A mixture of varied constitution, examined by Chevreul and Magendie, *An. de Ch. et Ph.* vol. ii.; Lameyran and Fremy, *Bulletin de Pharmacie,* vol. i.

(1097.) *Fæces.* Excrementitious matter rejected from the system as not affording nutriment. See Berzelius, *An. de Ch.* vol. lxi. Of animals, Fourcroy and Vauquelin, *An. de Ch.* vol. lvi.; Vauquelin, *Ibid.* vol. xxix.; Proust, *An. de Ch. et Ph.* vol. xiii.

Solid Parts of Animals.

(1098.) *Cerebral Matter.* This constitutes the brain, spinal marrow, and nerves of animals. See Vauquelin, *An. Phil.* vol. i.

(1099.) *Skin.* This consists of three distinct layers. The exterior is the *epidermis,* or cuticle; the central is the *rete mucosum;* and the interior, which covers the muscles, is the true skin. See Johnson, *An. Ch.* vol. i.

(1100.) *Tendons, Membranes,* and *Ligaments.* These seem to consist almost entirely of gelatine.

(1101.) *Wool, Feathers,* and *Hair* appear, from the experiments of Vauquelin, to contain a peculiar Animal substance, with oil, sulphur, silica, iron, phosphate, and sulphate of lime.

(1102.) *Horn.* The hoofs and nails of animals consist chiefly of gelatine, with a matter analogous to coagulated albumen.

(1103.) *Muscle.* This the flesh is chiefly fibrin; but besides small portions of other ingredients, it contains a peculiar substance called *osmazome;* this produces the odour and nutritive portion of soups.

(1104.) *Bone, Teeth,* and *Shell.* Bone consists of a cartilaginous mass, rendered solid by interposition of earthy matter and gelatine. The earthy matter is chiefly phosphate and carbonate of lime. Teeth and ivory seem, by the analysis of Allen and Pepys, to contain a much larger proportion of earthy substance, and less soluble matter. The shell of eggs, crabs, lobsters, and star-fish consists chiefly of carbonate of lime, with a little phosphate and Animal matter. In the shells of oysters and ordinary *Mollusca,* the phosphate of lime is absent.

Glandular and Membranous Secretions.

(1105.) *Lymph.* A colourless and transparent Liquid which circulates through a certain order of vessels, which seem to commence near the extreme ramifications of the arteries, and, uniting to form larger channels, return the lymph into the thoracic duct. See Brande, *Phil. Trans.* 1812; Leuret and Lassaigne, *Jour. de Ch. Méd.* vol. i. p. 155.

(1106.) *Synovia.* A Liquid secreted by a system of glands for the purpose of lubricating the joints, and the ligaments uniting them. See Margueron, *An. de Ch.* vol. xiv.; Vauquelin, *Jour. de Phar.* vol. iii.

(1107.) *Fœtal Liquids.* These Fluids are contained within the respective membranes surrounding the *fœtus.* The exterior being the *chorion,* the intermediate one the *allantois,* and the interior the *amnios.* See Dulong and Labillardiere, *Procès-Verbal de la Séance Publique de l'Ecole d'Alfort,* 1817; Lassaigne, *An. de Ch. et Ph.* vol. xvii. p. 295.

(1108.) *Humours of the Eye.* Of these there are three: 1st, the *aqueous,* in the anterior chamber between the transparent cornea and the iris, and also in the posterior chamber between the iris and the crystalline lens; 2dly, the *crystalline lens* itself; and 3dly, the *vitreous humour,* occupying a considerable space at the back of the crystalline lens. See the experiments of Chenevix, Nicolas, and Berzelius, *Bibl. Brit.* vol. liv.; *An. de Ch.* vol. liii. p. 307, vol. lxxxvii., and lxxxviii. p. 138.

(1109.) *Tears.* A limpid Fluid, analyzed by MM. Fourcroy and Vauquelin, *An. de Ch.* vol. x. p. 113.

(1110.) *Animal Mucus.* This Liquid is not confined to any particular part of the body, nor is it secreted by any perceptible glandular tissue, but the secretion takes place at the surface of all mucous membranes. It is most abundant in the nose, mouth, œsophagus, stomach, intestines, urinary passages, &c. See Fourcroy and Vauquelin, *An. de Ch.* vol. lxvii. p. 26; Berzelius, *Ibid.* vol. lxxxviii. p. 113.

(1111.) *Perspiration.* The Fluid issuing from the system under this name is at all times passing off, but sometimes as a vapour, when it is called the insensible perspiration; at other times in such quantities as to collect in moisture on the surface, when it is called sweat. See Berzelius, *An. de Ch.* vol. lxxix. p. 20; Seguin, *Ibid.* vol. xc. p. 14.

(1112.) *Milk,* a Fluid secreted by appropriate glands in animals of the class *Mammalia,* and designed for the sustenance of their young, contains three distinct proximate principles, the cream, curd, and whey. See Scheele, *Mém.* vol. ii.; Fourcroy and Vauquelin, *Mém. de l'Institut,* vol. vi. p. 22.

(1113.) *Spermatic Fluid.* For analyses, &c., see *Jour. de Phys., Jan.* 1784, p. 437; Vauquelin, *Ibid.* p. 58. sem. 2. 1791; Spallanzani, *Tracts,* 1799; Vauquelin, *An. de Ch.* vol. ix. p. 64; Prevost and Dumas, *An. de Hist. Nat.* vol. i. p. 167, 274

Concretions found in the Animal System, and all resulting more or less from diseased Action.

(1114.) *Biliary.* Gall stones, as they are called, are concretions formed in the gall bladder, and found there or in the biliary ducts, where they, at times, produce serious effects. See Thenard, *Mém. d'Arcueil*, vol. i.; Orfila, *An. de Ch.* vol. lxxxiv. p. 34; Caventou, *Jour. de Phar.* vol. iii. p. 369; Chevreul, *Jour. of Science*, vol. xviii. p. 403; Johnson, *An. Ch.* vol. ii.

(1115.) *Urinary.* From the constituent principles of the urine these calculi are separated either in the kidneys primarily, or in the bladder by deposition upon some nucleus. They exist also in the prostate gland, which in such cases is probably the seat of their origin. On this important subject consult Scheele's *Essays;* Wollaston, *Phil. Trans.* 1797 and 1810; Fourcroy and Vauquelin, *Mém. de l'Inst.* vol. ii. p. 112; *An. de Mus. Nat.* vol. i. p. 93; Pearson, *Phil. Trans.* 1798; Brande, *Phil. Trans.* 1802; Marcet, *Essay on the Chemical History and Medical Treatment of Calculous Disorders*, 1817; Prout, *Inquiry into the Nature and Treatment of Gravel, Calculus, &c.* 2d edit. 1825; Henry, *An. Phil.* vol. xv. p. 107.

(1116.) *Arthritic.* These calculi are formed chiefly at the joints of gouty individuals. See Wollaston, *Phil. Trans.* 1797; Vogel, *Bulletin de Pharmacie*, vol. iii. p. 568; Laugier, *Jour. de Chim. Méd.* vol. i. p. 6.

(1117.) *Salivary.* Concretions occur in the salivary glands. Those examined are chiefly from the larger animals. See Lassaigne, *An. de Ch. et Ph.* vol. xxx. p. 332; *Jour. de Pharm.* vol. iii. p. 208; Laugier, *Jour. de Chim. Méd.* vol. ii. p. 105.

(1118.) *Pancreatic.* Calculi have been found in the pancreas, but their nature is almost unknown.

(1119.) *Pineal.* In the pineal gland very small calculi are frequently met with; according to Vauquelin, they contain phosphate of lime and animal matter.

(1120.) *Pulmonary.* Fourcroy has mentioned these calculi as found in the lungs of old persons, especially of those subject to arthritic formations; and he states that they are sometimes expectorated in small fragments.

(1121.) *Intestinal.* Concretions, sometimes resulting from the intertexture of indigestible substances, and sometimes from the true deposition of calculous matter, are described by the following authors. Fourcroy and Vauquelin, *Mém. du Mus. d'Hist. Nat.* vol. iv. p. 329; Marcet, *op. cit.;* Braconnot, *An. de Ch. et Ph.* vol. xx. p. 194; Robert, *Jour. de Phar.* vol. vii. p. 161; Lassaigne, *Jour. de Chim. Méd.* vol. iii. p. 119; Dublanc, *Ibid.* p. 496.

CHAPTER III.

FUNCTIONS OF ANIMAL AND VEGETABLE LIFE.

Animal Life.

(1122.) The changes produced upon the various substances employed for the support of life are mainly connected with physiological researches, but to such researches Chemistry lends an important and even necessary assistance. Food and air are essential to the continuation of vitality. The former undergoes mastication, is mixed with saliva, and then descends into the stomach. It is there acted upon by the gastric juice, and the mass is termed chyme. The changes produced upon the food during the process of digestion have exercised the ingenuity of many physiologists. Among the most recent and most remarkable discoveries, is that made by Dr. Prout, and published in the *Philosophical Transactions* for 1824, of the production of hydrochloric Acid during this process. Passing thence into the intestines the bile and pancreatic juice are added to it. Here it is separated into excrementitious matter to be rejected from the system, and chyle to be absorbed by a peculiar set of vessels and applied to nutritive purposes.

From this period the chyle forms a part of the circulating system. From the lacteal vessels it is poured into the thoracic duct, but whether in the process it undergoes any further change is not certain. By the thoracic duct the chyle is conveyed to the larger veins proceeding to the heart; the blood is thence transmitted to the lungs where the essential process of aeration takes place. It is then returned to another cavity of the heart, from whence it is propelled through the arterial system to the utmost extremities of the frame, and having there supported and excited all the functions of vitality in every organ, it is returned again by the veins to be mixed with fresh supplies of energetic matter, and again diffused throughout the body.

The changes produced upon the blood by its passage through the lungs have formed the subject of numerous experiments. It seems well established that among these the absorption of oxygen is most important and extensive. Hence the necessity of the presence of oxygen Gas in air to fit it for respiration; and the diminution of that element which is found to take place in air that has undergone the process. Besides that portion of oxygen which goes to aerate the blood, and to prepare it for the arterial circulation, another portion is converted into carbonic Acid Gas, and emitted with the aerial mass that is returned into the atmosphere by expiration.

Vegetable Life.

(1123.) The germination of a seed is the first step towards Vegetable life. The seed itself consists of a cuticle enveloping the germ, and the cotyledons, or seed-lobes. The germ consists of the radicle and the plumula. Moisture, air, and a certain degree of heat are requisite for vegetation. The heat must exceed 32° Fahrenheit, and must not reach that of boiling water. Light, which is of first-rate importance to the growing plant, is injurious to germination. This process consists in the developement of the parts already named. The radicle descends into the earth in search of nutriment; the plumula expands into the stem and first elements of the future tree; the cotyledons afford nutriment in the early stages of vitality.

The process of Vegetable assimilation is this. The root absorbs moisture and soluble Vegetable matter, the food of the plant. The juices so imbibed are carried up through certain vessels, and spread by ramifications throughout the leaves, which, acting as aerating surfaces, or lungs, prepare the juices for strict assimilation. The juices are then transmitted to the proper vessels, returned through the inner bark, and thence employed in the increase of the plant. In these juices the peculiar properties of each plant chiefly reside.

PART IV.

Chemical Analysis. Connection with Mineralogy.

(1124.) The object of Chemical analysis is the separation of all compound bodies into their proximate or ultimate elements. For this purpose the first step is the application of tests for the purpose of ascertaining what the substance before the analyst may be, and what elements enter into its composition. When the presence of certain elements are ascertained, it becomes necessary to devise processes by which each of these may be separated from the rest and its quantity ascertained. The meeting with a substance no longer capable of qualitative division, and differing in properties from all substances previously known, is the discovery of a new element, and forms one of the highest rewards to the industry of the analytical Chemist. To enter upon these branches of the subject, even in abstract, would extend far beyond the limits to which we are confined. On the subject of tests the reader will find Payen and Chevallier, *Traitè des Rèactifs*, valuable guides. On the subject of analysis he will do well to consult the last Volume of M. Thenard's *Traitè de Chimie*, or a translation of it by Mr. Children. Most important information will always be obtained by consulting the numerous analyses in the periodical *Transactions* and *Journals*.

It has not been unusual in Treatises on Chemistry to insert descriptive catalogues of mineral substances. With such a plan we should not concur even if our limits permitted; for it would seem that by so doing the respective boundaries of Mineralogical and Chemical Science are confounded. It is the province of the Mineralogist to describe the substances with which he may meet according to all those external and physical characteristics by which minerals are distinguished from each other. In some, but in very few cases, Chemistry has made a further separation; but in all cases the history of a mineral is incomplete unless also its Chemical analysis be given. This it is the province of the Chemist to furnish. Thus the full description of the mineral results from the application of two distinct branches of Science, generally more or less united among the attainments of the same individual but not essentially coexistent. It would not be difficult to name Chemists of first-rate excellence who are not Mineralogists; nor, on the contrary, to point out able Mineralogists who are utterly incompetent to the analysis of the mineral they describe. Unquestionably the wants of the Mineralogist frequently demand the employment of the skill of the Chemist, but the Chemical examination of any substance artificially prepared and placed before him, is as justly the task of the latter, that of the native produce of the rock and the mine.

PART V.

Collection of Tables.

TABLE I.

Table of the Specific Gravity of Gases. See (75.)
(From Henry's *Elements.*)

Barometer 30°, Thermometer 60° Fahrenheit.

Names of Gases.	Sp. Gr.	Weight of 100 cubic inches.	Authorities.
		GrainsTroy	
Atmospheric air	1.0000	30.500	Shuckburgh.
Ditto	1.0000	30.199	Brande.
Simple Gases.			
Oxygen	1.1088	33.820	Allen and Pepys.
Ditto	1.1111	33.888	Thomson.
Ditto	1.1026	33.629	Berzelius & Dulong.
Chlorine	2.5082	76.500	Davy.
Ditto	2.5000	76.250	Thomson.
Iodine (vapour)	8.6780	244.679	Gay Lussac.
Ditto	8.6111	262.6308	Thomson.
Hydrogen	0.0694	2.116	Ditto.
Ditto	0.0688	2.098	Berzelius & Dulong.
Nitrogen	0.9722	29.625	Thomson.
Ditto	0.9760	29.768	Berzelius & Dulong.
Carbon (vapour)	0.4166	12.6083	Gay Lussac.
Sulphur (ditto)	1.1111	33.888	Thomson.
Phosphorus (ditto)	0.8333	25.416	Ditto.
Compound Combustible.			
Ammonia	0.5960	18.18	Allen and Pepys.
Ditto	0.5902	18.003	Thomson.
Ditto	0.5912	18.03	Berzelius & Dulong.
Carburetted hydrogen	0.5555	16.944	Thomson.
Ditto	0.5590	17.049	Berzelius & Dulong.
Olefiant	0.9722	26.652	Thomson.
Ditto	0.9804	29.90	Berzelius & Dulong.
Phosphuretted hydrogen	0.9027	27.537	Thomson.
Bihydroguret of phosphor.	0.9722	29.652	Ditto.
Sulphuretted hydrogen	1.1805	36.007	Ditto.
Bisulphuret of carbon (vapour)	2.6388	80.486	Ditto.
Arsenuretted hydrogen	0.5290	16.130	Tromdorff.
Cyanogen	1.8055	55.069	Gay Lussac.
Ditto	1.8188	55.473	Berzelius & Dulong.
Ether sulphuric (vapour)	2.5808	78.714	Ditto.
Ditto muriatic (ditto)	2.2190	67.679	Thomson.
Ditto hydriodic (ditto)	5.4750	166.987	Ditto.
Ditto chloric (ditto)	3.4750	105.257	Ditto.
Alcohol (ditto)	1.6004	48.812	Berzelius & Dulong.
Turpentine, oil of (ditto)	5.0130	152.896	Thomson.
Oxides.			
Aqueous vapour	0.6250	19.062	Gay Lussac.
Nitrous oxide	1.5277	46.597	Thomson.
Ditto	1.5273	46.582	Berzelius & Dulong.
Nitric oxide	1.0416	31.770	Thomson.
Carbonic oxide	0.9722	29.652	Ditto.
Ditto	0.9727	29.667	Berzelius & Dulong.
Acids.			
Carbonic	1.5277	46.597	Thomson.
Ditto	1.5240	46.481	Berzelius & Dulong.
Chlorocarbonic (phosgene)	3.4722	105.902	Thomson.
Chlorocyanic (vapour)	2.1520	65.636	Ditto.
Fluoboric	2.3611	72.013	Ditto.
Fluosilicic	3.611	110.138	Ditto.
Hydriodic	4.340	132.378	Ditto.
Hydrocyanic	0.9375	28.572	Ditto.
Muriatic	1.2847	39.183	Ditto.
Nitric	3.75	114.375	Davy.
Sulphurous	2.2222	67.777	Thomson.
Sulphuric (vapour)	2.7777	84.698	Ditto.

"Gay Lussac's Table, which is more copious, but in which the numbers are not reduced to a mean of the Barometer and Thermometer, is copied into Thomson's *Annals*, vol. ix. p. 18. A Table, by Professor Minecke of Halle, is inserted in the *Journal of Science*, vol. iii. p. 415. Dr. Thomson's elaborate Paper on this subject is printed in the XVIth Volume of *Annals of Philosophy;* and Berzelius and Dulong's in the XVth Volume of *An. de Chi et Ph.*"

TABLE II.

Exhibiting the Specific Gravity of Muriatic Acid of determinate Strengths.

Atoms of Acid.	Atoms of Water.	Acid in 100.	Specific Gravity.
1	6	40.659	1.203
1	7	37.000	1.179
1	8	33.945	1.162
1	9	31.346	1.149
1	10	29.134	1.139
1	11	27.206	1.1285
1	12	25.517	1.1197
1	13	24.026	1.1127
1	14	22.700	1.1060
1	15	21.512	1.1008
1	16	20.442	1.0960
1	17	19.474	1.0902
1	18	18.590	1.0860
1	19	17.790	1.0820
1	20	17.051	1.0780

From Thomson's *First Principles,* vol. i. p. 87.

TABLE III.

Of the Quantity of real or dry Muriatic Acid in 100 *parts of the liquid Acid, at successive Specific Gravities.* By Dr. Ure, Thomson's *Annals*, vol. x. p. 371

Sp. Gr.	Acid in 100.	Sp. Gr.	Acid in 100.	Sp. Gr.	Acid in 100.
1.1920	28.30	1.1272	18.68	1.0610	9.05
1.1900	28.02	1.1253	18.39	1.0590	8.77
1.1881	27.73	1.1233	18.11	1.0571	8.49
1.1863	27.45	1.1214	17.83	1.0552	8.21
1.1845	27.17	1.1194	17.55	1.0533	7.92
1.1827	26.88	1.1173	17.26	1.0514	7.64
1.1808	26.60	1.1155	16.98	1.0495	7.36
1.1790	26.32	1.1134	16.70	1.0477	7.07
1.1772	26.04	1.1115	16.41	1.0457	6.79
1.1753	25.75	1.1097	16.13	1.0438	6.51
1.1735	25.47	1.1077	15.85	1.0418	6.23
1.1715	25.19	1.1058	15.56	1.0399	5.94
1.1698	24.90	1.1037	15.28	1.0380	5.66
1.1679	24.62	1.1018	15.00	1.0361	5.38
1.1661	24.34	1.0999	14.72	1.0342	5.09
1.1642	24.05	1.0980	14.43	1.0324	4.81
1.1624	23.77	1.0960	14.15	1.0304	4.53
1.1605	23.49	1.0941	13.87	1.0285	4.24
1.1587	23.20	1.0922	13.58	1.0266	3.96
1.1568	22.92	1.0902	13.30	1.0247	3.68
1.1550	22.64	1.0883	13.02	1.0228	3.39
1.1531	22.36	1.0863	12.73	1.0209	3.11
1.1510	22.07	1.0844	12.45	1.0190	2.83
1.1491	21.79	1.0823	12.17	1.0171	2.55
1.1471	21.51	1.0805	11.88	1.0152	2.26
1.1452	21.22	1.0785	11.60	1.0133	1.98
1.1431	20.94	1.0765	11.32	1.0114	1.70
1.1410	20.66	1.0746	11.04	1.0095	1.41
1.1391	20.37	1.0727	10.75	1.0076	1.13
1.1371	20.09	1.0707	10.47	1.0056	0.85
1.1351	19.81	1.0688	10.19	1.0037	0.56
1.1332	19.53	1.0669	9.90	1.0019	0.28
1.1312	19.24	1.0649	9.62	1.0000	0·00
1.1293	18.96	1.0629	9.34		

* Note by Dr. Henry. The data on which this Table is founded were obtained by saturating different bases with known quantities of muriatic Acid, Specific Gravity 1.192, and ascertaining the weight of the dry products. For example, 100 grains of such Acid gave 60.61 grains of dry common salt, which, on the old theory, may consist of 32.31 soda + 28.3 muriatic Acid, or, according to the new view, of 24.244 sodium + 36.366 chlorine, equivalent to 37.376 muriatic Acid. Admitting, then, the data to be correct, the composition of muriatic Acid of different densities will require the numbers to be altered, to suit the views of those who embrace the new doctrine respecting chlorine. This may be done by the rule of proportion; for as 37.376 is to 28.3, so is any number below 28.3 in the Table to the number required."

TABLE *IV.

Table of the Quantity of Oil of Vitriol (Specific Gravity 18.8485) *and of dry Sulphuric Acid in* 100 *parts by weight of diluted Acid at different densities.* By Dr. Ure, Brande's *Journal,* vol. iv. p. 122.

Liquid.	Sp. Gr.	Dry.	Liquid.	Sp. Gr.	Dry.
100	1.8485	81.54	50	1.3884	40.77
99	1.8475	80.72	49	1.3788	39.95
98	1.8460	79.90	48	1.3697	39.14
97	1.8439	79.09	47	1.3612	38.32
96	1.8410	78.28	46	1.3530	37.51
95	1.8376	77.46	45	1.3440	36.69
94	1.8336	76.65	44	1.3345	35.88
93	1.8290	75.83	43	1.3255	35.06
92	1.8233	75.02	42	1.3165	34.25
91	1.8179	74.20	41	1.3080	33.43
90	1.8115	73.39	40	1.2999	32.61
89	1.8043	72.57	39	1.2913	31.80
88	1.7962	71.75	38	1.2826	30.98
87	1.7870	70.94	37	1.2740	30.17
86	1.7774	70.12	36	1.2654	29.35
85	1.7673	69.31	35	1.2572	28.54
84	1.7570	68.49	34	1.2490	27.72
83	1.7465	67.68	33	1.2409	26.91
82	1.7360	66.86	32	1.2334	26.09
81	1.7245	66.05	31	1.2260	25.28
80	1.7120	65.23	30	1.2184	24.46
79	1·6993	64.42	29	1.2108	23.65
78	1.6870	63.60	28	1.2032	22.83
77	1.6750	62.78	27	1.1956	22.01
76	1.6630	61.97	26	1.1876	21.20
75	1.6520	61.15	25	1.1792	20.38
74	1.6415	60.34	24	1.1706	19.57
73	1.6321	59.52	23	1.1626	18.75
72	1.6204	58.71	22	1.1549	17.94
71	1.6090	57.89	21	1.1480	17.12
70	1.5975	57.08	20	1.1410	16.31
69	1.5868	56.26	19	1.1330	15.49
68	1.5760	55.45	18	1.1246	14.68
67	1.5648	54.63	17	1.1165	13.86
66	1.5503	53.82	16	1.1090	13.05
65	1.5390	53.00	15	1.1019	12.23
64	1.5280	52.13	14	1.0953	11.41
63	1.5170	51.37	13	1.0887	10.60
62	1.5066	50.55	12	1.0809	9.78
61	1.4960	49.74	11	1.0743	8.97
60	1.4860	48.92	10	1.0682	8.15
59	1.4760	48.11	9	1.0614	7.34
58	1.4660	47.29	8	1.0544	6.52
57	1.4560	46.48	7	1.0477	5.71
56	1.4460	45.66	6	1.0405	4.89
55	1.4360	44.85	5	1.0336	4.08
54	1.4265	44.03	4	1.0268	3.26
53	1.4170	43.22	3	1.0206	2.446
52	1.4073	42.40	2	1.0140	1.63
51	1.3977	41.58	1	1.0740	0.8154

TABLE IV.

Mr. Dalton's Table of the Quantity of real Acid in 100 *parts of liquid Sulphuric Acid; at the temperature of* 60° *Fahrenheit.*

Atoms of Acid+Water.	Real Acid per cent. by weight.	Real Acid per cent. by measure.	Specific Gravity.	Boiling Point.
1 + 0	100	Unknown.	Unknown.	Unknown.
1 + 1	81	150	1.850	620°
	80	148	1.849	605
	79	146	1.848	590
	78	144	1.847	575
	77	142	1.845	560
	76	140	1.842	545
	75	138	1.838	530
	74	135	1.833	515
	73	133	1.827	501
	72	131	1.819	487
	71	129	1.810	473
	70	126	1.801	460
	69	124	1.791	447
1 + 2	68	121	1.780	435
	67	118	1.769	422
	66	116	1.757	410
	65	113	1.744	400
	64	111	1.730	391
	63	108	1.715	382
	62	105	1.699	374
	61	103	1.684	367
	60	100	1.670	360
1 + 3	58.6	97	1.650	350
	50	76	1.520	290
	40	56	1.408	260
1 + 10	30	39	1.30+	240
1 + 17	20	24	1.200	224
1 + 38	10	11	1.10−	218

TABLE V.

Table of the Precipitates produced by Solutions of the Hydrosulphates of Potassa, Soda, and Ammonia with different Saline Solutions. Pelletan, *Dict. de Chimie.*

Salts.	Colour of Precipitate.	Nature of Precipitate.
Of Zircon	White	Zirconia.
Of Alumina	Ditto	Alumina.
Of Glycina and Yttria	No precip.	———
Of all the IId Class	Ditto	———
Of Manganese	Dirty white	A hydrosulphate or a sulphuretted hydrosulphate.
Of Zinc	White	A hydrosulphate
Of Iron	Black	A hydrosulphate or a sulphuretted hydrosulphate.
Of Antimony	Orange	Ditto.
Of Protox. of Tin	Chocolate	A hydrosulphate
Of Deutox. of Tin	Yellow	Ditto.
Of Cadmium	Ditto	A sulphuret.
Of Arsenic	Ditto	Ditto.
Of Molybdinum	Reddish brown	Ditto.
Of Chromium	Green	Ditto.
Of Columbium	Chocolate	Ditto.
Of Uranium	Brown	Ditto.
Of Cerium	Ditto	Ditto.
Of Cobalt	Black	Ditto.
Of Titanium	Bottle-green	Ditto.
Of Bismuth	Black	Ditto.
Of Copper	Ditto	Ditto.
Of Tellurium	Ditto	Ditto.
Of Nickel	Ditto	Ditto.
Of Lead	Ditto	Ditto.
Of Mercury	Black brown	Ditto.
Of Silver	Black	Ditto.
Of Palladium	Ditto	Ditto.
Of Platinum	Ditto	Ditto.
Of Gold	Ditto	Ditto.

TABLE VI.

Table of the real or dry Nitric Acid in 100 *parts of the liquid Acid at successive Specific Gravities,* by Dr. Ure, *Quarterly Journal,* vol. iv. p. 297. (See Art. 446.)

Sp. Grav.	Acid in 100.	Sp. Grav.	Acid in 100.	Sp. Grav.	Acid in 100.
1.5000	79.700	1.3783	52.602	1.1833	25.504
1.4980	78.903	1.3732	51.805	1.1770	24.707
1.4960	78.106	1.3681	51.068	1.1709	23.910
1.4940	77.309	1.3630	50.211	1.1648	23.113
1.4910	76.512	1.3579	49.414	1.1587	22.316
1.4880	75.715	1.3529	48.617	1.1526	21.519
1.4850	74.918	1.3477	47.820	1.1465	20.722
1.4820	74.121	1.3427	47.023	1.1403	19.925
1.4790	73.324	1.3376	46.226	1.1345	19.128
1.4760	72.527	1.3323	45.429	1.1286	18.331
1.4730	71.730	1.3270	44.632	1.1227	17.534
1.4700	70.933	1.3216	43.835	1.1168	16.737
1.4670	70.136	1.3163	43.038	1.1109	15.940
1.4640	69.339	1.3110	42.241	1.1051	15.143
1.4600	68.542	1.3056	41.444	1.0993	14.346
1.4570	67.745	1.3001	40.647	1.0935	13.549
1.4530	66.948	1.2947	39.850	1.0878	12.752
1.4500	66.155	1.2887	39.053	1.0821	11.955
1.4460	65.354	1.2826	38.256	1.0764	11.158
1.4424	64.557	1.2765	37.459	1.0708	10.361
1.4385	63.760	1.2705	36 662	1.0651	9.564
1.4346	62.963	1.2644	35.865	1.0595	8.767
1.4306	62.166	1.2583	35.068	1.0540	7.970
1.4269	61.369	1.2523	34.271	1.0485	7.173
1.4228	60.572	1.2462	33.474	1.0430	6.376
1.4189	59.775	1.2402	32.667	1.0375	5.579
1.4147	58.978	1.2341	31.880	1.0320	4.782
1.4107	58.181	1.2277	31.083	1.0267	3.985
1.4065	57.384	1.2212	30.286	1.0212	3.188
1.4023	56.587	1.2148	29.489	1.0159	2.391
1.3978	55.790	1.2084	28.692	1.0106	1.594
1.3945	54.993	1.2019	27.895	1.0053	0.797
1.3882	54.196	1.1958	27.098		
1.3833	53.399	1.1895	26.301		

Note by Dr. Henry. "In this Table, the real Acid in nitric Acid f Specific Gravity 1.5, is rated at 4.8 per cent. more than is con-ained in it according to Dr. Wollaston and Mr. Phillips, the mean f whose numbers is 25.1 water + 74.9 Acid in 100 parts of Acid of hat density. The numbers in the Table will, I believe, however, be ery near the truth, if reduced at the rate of 6 per cent. Thus 6 er cent. on 79.7 is 4.782; and 79.7 – 4.782 = 74.918, which is ery near the true number."

TABLE VII.

Of the Specific Gravities of certain Atomic Combinations of Nitric Acid and Water, by Dr. Thomson, *First Principles,* vol. i. p. 114. (See Art. 446.)

Atoms of Acid	Atoms of Water.	Acid in 100.	Specific Gravity.
1	1	85.714	1.55
1	2	75.000	1.4855
1	3	66.668	1.4546
1	4	60.000	1.4237
1	5	54.545	1.3928
1	6	50.000	1.3692
1	7	46.260	1.3456
1	8	42.857	1.3220
1	9	40.000	1.3032
1	10	37.500	1.2844
1	11	35.294	1.2656
1	12	32.574	1.2495
1	13	31.579	1.2334
1	14	30.000	1.2173
1	15	28.571	1.2012

TABLE VIII.

Table exhibiting the Proportion, by Volume, of Aqueous Vapour existing in any Gas in contact with Water at the corresponding Temperatures, and at the mean Barometric Pressure of 30 *Inches.*

40°	.00933	61°	.01923
41	.00973	62	.01980
42	.01013	63	.02050
43	.01053	64	.02120
44	.01093	65	.02190
45	.01133	66	.02260
46	.01173	67	.02330
47	.01213	68	.02406
48	.01253	69	.02483
49	.01293	70	.02566
50	.01333	71	.02653
51	.01380	72	.02740
52	.01426	73	.02830
53	.01480	74	.02923
54	.01533	75	.03020
55	.01586	76	.03120
56	.01640	77	.03220
57	.01693	78	.03323
58	.01753	79	.03423
59	.01810	80	.03533
60	.01866		

From Faraday *On Manipulation,* p. 381.

TABLE IX.

Of the Specific Gravity of Alcohol at various Degrees of Dilution.

100 Parts.		Specific Gravity.		100 Parts.		Specific Gravity.		100 Parts.		Specific Gravity.		100 Parts.		Specific Gravity.	
Alcohol.	Water.	at 68°	at 60°	Alcohol.	Water.	at 68°	at 60°	Alcohol.	Water.	at 68°	at 60°	Alcohol.	Water.	at 68°	at 60°
100	0	.791	.796	74	26	.859	.863	48	52	.919	.922	23	77	.968	.970
99	1	.794	.798	73	27	.861	.865	47	53	.921	.924	22	78	.970	.972
98	2	.797	.801	72	28	.863	.867	46	54	.923	.926	21	79	.971	.973
97	3	.800	.804	71	29	.866	.870	45	55	.925	.928	20	80	.973	.974
96	4	.803	.807	70	30	.868	.871	44	56	.927	.930	19	81	.974	.975
95	5	.805	.809	69	31	.870	.874	43	57	.930	.933	18	82	.976	
94	6	.808	.812	68	32	.872	.875	42	58	.932	.935	17	83	.977	
93	7	.811	.815	67	33	.875	.879	41	59	.934	.937	16	84	.978	
92	8	.813	.817	66	34	.877	.880	40	60	.936	.939	15	85	.980	
91	9	.816	.820	65	35	.880	.883	39	61	.938	.941	14	86	.981	
90	10	.818	.822	64	36	.882	.886	38	62	.940	.943	13	87	.983	
89	11	.821	.825	63	37	.885	.889	37	63	.942	.945	12	88	.985	
88	12	.823	.827	62	38	.887	.891	36	64	.944	.947	11	89	.986	
87	13	.826	.830	61	39	.889	.893	35	65	.946	.949	10	90	.987	
86	14	.828	.832	60	40	.892	.896	34	66	.948	.951	9	91	.988	
85	15	.831	.835	59	41	.894	.898	33	67	.950	.953	8	92	.989	
84	16	.834	.838	58	42	.896	.900	32	68	.952	.955	7	93	.991	
83	17	.836	.840	57	43	.899	.903	31	69	.954	.957	6	94	.992	
82	18	.839	.843	56	44	.901	.904	30	70	.956	.958	5	95	.994	
81	19	.842	.846	55	45	.903	.906	29	71	.957	.960	4	96	.995	
80	20	.844	.848	54	46	.905	.908	28	72	.959	.962	3	97	.997	
79	21	.847	.851	53	47	.907	.910	27	73	.961	.963	2	98	.998	
78	22	.849	.853	52	48	.909	.912	26	74	.963	.965	1	99	.999	
77	23	.851	.855	51	49	.912	.915	25	75	.965	.967	0	100	1.000	
76	24	.853	.857	50	50	.914	.917	24	76	.966	.968				
75	25	.856	.860	49	51	.917	.920								

This Table is by Lowitz, Crell's *An*. 1796, vol. i. p. 202: the column for temperature 60° is a convenient addition by Dr. Thomson. For more extensive Tables, see Blagden, *Ph. Tr*. 1790, and Gilpin, *Ph. Tr*. 1794. Gilpin considered his strongest alcohol of .825, temperature 60°, to consist of 100 parts of alcohol, Specific Gravity 814, + 4.5 of water. See also Tralles, *Mém. Acad. Berol.* 1811, or Gilbert's *Annalen*, vol. xxxviii. p. 369.

TABLE X.

Table for reducing the Degrees of Baume's Hydrometer to the common Standard.

Baume's Hydrometer for Liquids lighter than Water. Temperature 55° Fahrenheit, or 10° Reaumur.							
Deg.	Sp. Gr.	Deg.	Sp. Gr.	Deg.	Sp. Gr.	Deg.	Sp. Gr.
10.	1.000	18...	.942	26...	.892	34..	.847
11..	.990	19...	.935	27...	.886	35..	.842
12..	.985	20...	.828	28...	.880	36..	.837
13..	.977	21...	.922	29...	.874	37..	.832
14..	.970	22...	.915	30...	.867	38..	.327
15..	.963	23...	.909	31...	.861	39..	.822
16..	.955	24...	.903	32...	.856	40..	.817
17..	.949	25...	.897	33...	.852		

Baume's Hydrometer for Liquids heavier than Water. Temperature 55° Fahrenheit, or 10° Reaumur.							
Deg.	Sp. Gr.	Deg.	Sp. Gr.	Deg.	Sp. Gr.	Deg.	Sp. Gr
0.	1.000	21..	1.170	42..	1.414	63.	1.779
3.	1.020	24..	1.200	45..	1.455	66.	1.848
6.	1.040	27..	1.230	48..	1.500	69.	1.920
9.	1.064	30..	1.261	51..	1.547	72.	2.000
12.	1.089	33..	1.295	54..	1.594		
15.	1.114	36..	1.333	57..	1.659		
18.	1.140	39..	1.373	60..	1.717		

TABLE XI.

Table of the Properties of the Metals.

Name.	When discovered.	By whom.	Colour.	Specific Gravity.	Fusing point, Fahrenheit.	Scale of ductility.	Scale of malleability.	Tenacity.	Ratio of hardness.
Gold......	Known from the earliest ages.	....	Pure yellow.	19.257	5237	1	1	68.216	8
Silver.....		....	White.	10.474	3677	2	2	85.062	6
Iron......		....	Blue-grey.	7.788	17977	4	8	269.659	3
Copper....		....	Red.	8.895	4587	5	3	157.399	5
Mercury...		....	White.	13.568	—39	..	..	....	None.
Lead......		....	Blue.	11.352	594	8	6	....	14
Tin.......		....	White.	7.291	442	7	4	24.200	12
Zinc.........	1541	Paracelsus.	Bluish-white.	6.661	700	6	7	12.720	9
Bismuth.....	1520	Agricola.	Yellowish-white.	9.822	476	..	..	....	7
Antimony....	XVth Cent.	B. Valent.	Bluish-white.	6.702	932	..	..	....	10
Arsenic......	1723	Brandt.	Grey.	8.308	...	..	..	....	13
Cobalt.......	..	Ditto.	Grey-white.	8.538	16677	..	..	....	11
Platinum.....	1741	Wood.	Bluish-white.	21.500	G. B. P.	3	5	124.090	4
Nickel.......	1751	Croustedt.	White.	8.279	21877	9	9	....	..
Manganese...	1774	Scheele.	Grey-white.	5.850	Ditto.	..	..	....	2
Tungsten....	1781	D'Elhuyart.	....	17.600	G. B. P.	..	..	....	1
Tellurium....	1782	Muller.	....	6.115	....	..	..	....	..
Molybdenum.	Ditto.	Hjelm.	Grey.	7.400	G. B. P.	..	..	....	..
Titanium.....	1781	Gregor.	Red.	....	Ditto.	..	..	....	..
Uranium.....	1789	Klaproth.	Grey.	9.000	Ditto.	..	..	....	..
Chromium...	1797	Vauquelin.	....	....	Ditto.	..	..	....	..
Columbium...	1802	Hatchett.	....	....	Ditto.	..	..	....	..
Palladium....	1803	Wollaston.	Bluish-white.	11.300	....	10	10	....	1
Rhodium.....	Ditto.	Ditto.	Greyish-white.	....	G. B. P.	..	..	....	..
Iridium......	Ditto.	Descotils.	....	....	Ditto.	..	..	....	..
Osmium.....	Ditto.	Tenant.	Bluish-black.	....	....	..	..	....	..
Cerium......	1804	Berzelius.	Grey-white.	....	G. B. P.	..	..	....	..
Potassium..	1807	Davy.	Ditto.	0.865	136	..	..	....	100
Sodium....			Ditto.	0.972	194	..	..	....	100
Barium....			....	....	....	..	..	....	..
Strontium..			....	....	....	..	..	....	..
Calcium...			....	....	....	..	..	....	..
Cadmium...	1818	Stromeyer.	White.	8.604	....	11	11	....	..
Lithium....	1818	Arfvedson.	....	....	....	..	..	....	..

TABLE XII. The Atomic Weights, Constitutions, &c. of Bodies.

The following Table serves partly as a reference by which to find any substance mentioned in this Treatise. In thus employing it, the reader will be immediately struck with the very general and limited nature of the description of each individual substance, which it is possible to convey in a Treatise of this extent; but with this unavoidable disadvantage, the unity of method is preserved, and the outline of a plan for what may be enlarged by any one into a more ample Treatise is developed. The Table is also designed to show the state of our knowledge with regard to the combining proportions, or our belief respecting the atomic constitution of substances. The nomenclature made use of has been already explained in Art. (110.), (111.), and (112.) It possesses the following advantages. In Oxides, Iodides, Chlorides, Sulphurets, Salts, &c. it invariably employs such a name as will point out at once the degree of oxidation, &c. In all Salts it points out with precision the atomic proportion between the Acid and the base; and also the degree of oxygenation of the base. The Greek prefixes Prot-, Deut-, Trit-, Tetart-, &c. are solely confined to the degree of oxygenation; while in the Iodides, Sulphurets, &c. bi-, ter-, quater-, &c. are employed as in the case of Salts stated in the Paradigma. (111.) The practical necessity for this will be found by any one who shall try to interchange these two terms; and it is from such compulsion that we depart from our original design mentioned in (111.), of applying these Greek terms to the Chlorides, Sulphurets, &c. Our nomenclature does not, however, extend to a description of the water in each Salt.

It may be objected that these descriptive names are inconveniently long; let us, therefore, fairly examine one or two of the longest names in the following Table, and inquire whether the advantage of a true atomic description is not sufficient to justify the change. The following, for example, is the strongest case that could be proposed against us. Persesquisulphate of iron is called Hemi-deuto-semi-bisulphate of Iron. The word Persesquisulphate implies that the Salt contains the Peroxide of Iron, but then we know not the proportion between the atoms of Iron and of Oxygen. By Sesqui we learn conventionally that there is base one atom + Acid 1½ atom, or, perhaps, only that there is half as much more Acid in this Salt as in the Sulphate. The name we employ tells us more. As an invariable rule we take the Greek commencement of the name *Hemi-deuto-*, from this we learn that the oxide contains Oxygen 1½ atom + metal 1 atom. From the next portion *semi-bi-* we learn that the Salt contains Acid 1½ atom + base 1 atom, and from the remainder of the word the nature of the Acid and of the base are obvious.

Deuto-semi-bisulphate of Uranium may be similarly analyzed, and will be found equally explanatory; while Sulphate of Uranium, the common name, neither expresses the degree of oxidation of the Metal, nor the atomic constitution of the Salt.

The less important classes of Salts are not given at length for want of space. A valuable Table of Double Salts given in Thomson's *First Principles* is omitted for the same reason.

The main authority admitted for the following Table is *The First Principles* of Dr. Thomson: this Work has been employed wherever it was available. It was at first designed to cite the exact authority for every number here inserted, but here also our unavoidable limits of space have checked us. Hydrogen is the unit to which all other atomic weights are referred; but should any one prefer the oxygen scale, it is easy to divide all the numbers by 8. In the column headed State, S means solid. L, Liquid. G, a Gas. V, vapour. C, crystallized. H, hydrous. A, anhydrous.

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions by Weight	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Acetates.						
Alumina, Acetate of......	C.&H.	Acetic Acid	1	50	77	(559)
		Alumina	1	18		
		Water..........	1	9		
Ammonia, Acetate of.....	C.&H.	Acetic Acid.....	1	50	130	(469)
		Ammonia.......	1	17		
		Water..........	7	63		
Baryta, Acetate of.......	C.&H.	Acetic Acid	1	50	155	(584)
		Baryta	1	78		
		Water..........	3	27		
Cadmium, Protacetate of.	C.&H.	Acetic Acid	1	50	132	(653)
		Protox. Cadm....	1	64		
		Water	2	18		
Copper, Protacetate of....	C.&H.	Acetic Acid	1	50	99	(831)
		Prot.Cop. (black)	1	40		
		Water..........	1	9		
Ditto, Proto-semi-dinacet-of (Subsesquacetate)	C.&H.	Acetic Acid	1½	50	137	(Do.)
		Protox. Cop.	1	60		
		Water..........	3	27		
Ditto, Proto-dinacetate of.	C.&H.	Acetic Acid	1	50	184	(Do.)
		Protox. Cop.	2	80		
		Water..........	6	54		
Ditto, Proto-trinacetate of.	C.&H.	Acetic Acid.....	1	50	188	(Do.)
		Protox. Cop.	3	120		
		Water..........	2	18		
Iron, Protacetate of......	C.&H.	Acetic Acid	1	50	113	(657)
		Protox. Iron.....	1	35		
		Water	3	27		
Lead, Protacetate of.....	C.&H.	Acetic Acid	1	50	189	(861)
		Protox. Lead....	1	112		
		Water..........	3	27		
Ditto, Proto-dinacet. of...	C.&H.	Acetic Acid	1	50	364	(Do.)
		Protox. Lead....	2	224		
		Water..........	3	27		
Ditto, Proto-trinacet. of ..	C.&H.	Acetic Acid.....	1	50	404	(Do.)
		Protox. Lead	3	336		
		Water..........	2	18		
Lime, Acetate of.........	C.&H.	Acetic Acid	1	50	132	(559)
		Lime	1	28		
		Water..........	6	54		
Magnesia, Acetate of.....	C.&H.	Acetic Acid	1	50	115	(536)
		Magnesia	1	20		
		Water	5	45		
Manganese, Protacetate of (Acetate T.)	C.&H.	Acetic Acid	1	50	122	(645)
		Protox. Mang....	1	36		
		Water..........	4	36		
Mercury, Protacetate.....	C.&H.	Acetic Acid	1	50	294	(879)
		Protox. Merc. .	1	208		
		Water..........	4	36		
Nickel, Protacetate of....	C.&H.	Acetic Acid	1	50	129	(892)
		Protox. Nickel...	1	34		
		Water..........	5	45		
Potassa, Protacetate of...	C.&H.	Acetic Acid	1	50	116	(634)
		Protox. Potassium	1	48		
		Water..........	2	18		
Potassa, Proto-binacet. of.	C.&H.	Acetic Acid	2	100	202	[illegible]
		Protox. Potassium	1	48		
		Water..........	6	54		
Silver, Protacetate of	C.&H.	Acetic Acid	1	50	168	[illegible]
		Protox. Silver...	1	118		
Soda, Protacetate of	C.&H.	Acetic Acid	1	50	136	[illegible]
		Protox. Sodium..	1	32		
		Water..........	6	54		
Strontia, Protacetate of ..	C.&H.	Acetic Acid	1	50	111	[illegible]
		Strontia	1	52		
		Water	1	9		
Zinc, Protacetate of......	C.&H.	Acetic Acid.....	1	50	163	[illegible]
		Protox. Zinc	1	50		
		Water..........	7	63		
Acetous Fermentation......	..	....	..	..	..	[illegible]
Acids.						
Acetic	A.	Oxygen.........	3	24	50	[illegible]
		Hydrogen	2	2		
		Carbon	4	24		
Ditto....................	C.&H.	Acetic Acid	1	50	59	(Do.)
		Water..........	1	9		
Amniotic	..	....	..	..	..	[illegible]
Antimonious (see Hemi-deutoxide of A.)	..	....	..	..	..	[illegible]
Antimonic (see Deutoxide of A.)	..	....	..	..	..	[illegible]
Arsenic (see Tritoxide of A.)	..	....	..	..	..	[illegible]
Arsenious (see Deutoxide of A.)	..	....	..	..	..	[illegible]
Benzoic (Flowers of Benjamin)...............	..	Oxygen.........	3	24	120	[illegible]
		Hydrogen	6	6		
		Carbon.........	15	90		
Boracic	A.	Oxygen.........	2	16	40	[illegible]
		Boron	1	24		
Ditto	C.&H.	Acid	1	40	58	(Do.)
		Water..........	2	18		
Boro-fluoric	..	Fluorine........	1	18	34	[illegible]
		Boron	2	16		
Camphoric	..	....	..	..	..	[illegible]
Carbonic	G.	Oxygen.........	2	16	22	[illegible]
		Carbon	1	6		
Chloric	..	Oxygen.........	5	40	76	[illegible]
		Chlorine	1	36		
Chloriodic	..	Iodine	1	24	196	[illegible]
		Chlorine	2	172		
Chloro-cyanic	..	Cyanogen......	9	26	62	[illegible]
		Chlorine	1	36		
Chloro-carbonic	..	Carbonic Oxide .	1	14	50	[illegible]
		Chlorine	1	36		
Chromic (see Tritox. of Chrom.)	..	....	..	..	..	[illegible]
Citric	A.	Hydrogen.......	2	2	58	[illegible]
		Carbon	4	24		
		Oxygen........	4	32		

TABLE XII. *continued.*

Substance.	State.	Elements.	No. of Atoms	Constituent Proportions by Weight	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Strontian, Arseniate of ...	..	Arsenic Acid.... Strontian........ Water..........	1 1 8	62 52 72	186	
Silver, Prot-hemi-diarseni. of (Subsesquarsen. T.)	A.	Arsenic Acid.... Protox. Silver...	1 1½	62 177	239	
Zinc, Prot-arseniate of....	..	Arsenic Acid.... Protox. Zinc..... Water..........	1 1 8	62 42 72	176	
Arsenites.						
Lime, Arsenite of........	A.	Arsenious Acid.. Lime...........	1 1	54 28	82	(708)
Potassa, Arsenite of......	..	Arsenious Acid.. Potassa.........	1 1	54 48	102	
Silver, Arsenite of........	..	Arsenious Acid.. Protox. Silver...	1 1	54 118	172	
Soda, Arsenite of........	..	Arsenious Acid.. Soda...........	1 1	54 32	86	
Asparagin...............	..		..	..	..	(1029)
Atrophia...............	..		..	..	..	(1013)
Balsams...............	..		..	..	..	(1019)
Baryum...............	S.		..	..	70	(574)
Baryta (see Protoxide of Baryum.)............	..		..	..	78	(575)
Benzoates...............	..		..	..	..	(981)
Ammonia, Benzoate of....	S.	Benzoic Acid.... Ammonia....... Water..........	1 1 1	120 17 9	146	
Potassa, Benzoate of.....	..	Benzoic Acid.... Potassa......... Water..........	1 1 3	120 48 27	195	
Lead, Proto-benzoate of ..	..	Benzoic Acid.... Protox. Lead.... Water..........	1 1 1	120 112 9	241	
Bassorine...............	..		..	..	..	(1042)
Bile...............	..		..	..	..	(1091)
Biliary Calculi..........	..		..	..	..	(1114)
Bismuth...............	S.		..	..	72	(810)
Bitumens...............	..		..	..	..	(1025)
Blood...............	..		..	..	..	(1094)
Borates................	..		..	..	..	(341)
Ammonia, Borate of	C.	Boracic Acid.... Ammonia....... Water..........	1 1 2	24 17 18	59	
Baryta, Biborate of	A.	Boracic Acid.... Baryta..........	2 1	48 78	126	
Magnesia, Biborate of....	A.	Boracic Acid.... Magnesia.......	2 1	48 20	68	
Soda, Biborate of (Borax)	C.	Boracic Acid.... Soda........... Water..........	2 1 8	48 32 72	152	
Borax...............	S.		1	8	8	(324)
Brucia...............	..		..	..	..	(1008)
Bryonine...............	..		..	..	..	(1043)
Cadmium...............	S.		..	..	56	(684)
Caffein...............	..		..	..	..	(1059)
Calcium...............	S.		..	..	20	(541)
Calculi...............	..		..	..	..	(1114)
Calomel (see Chloride of Mercury)............	..		..	..	236	(874)
Camphor...............	..		..	..	..	(1022)
Caoutchouc...............	..		..	..	..	(1020)
Carbon...............	S.		..	..	..	(297)
Carbonates................	..		..	..	..	(312)
Ammonia, Carbonate of ..	S.&A.	Carbonic Acid... Ammonia.......	1 1	22 17	39	
Ditto, Hemi-bicarbonate of	S.	Carbonic Acid... Ammonia....... Water..........	1½ 1 1	33 17 9	59	
Ammonia, Bicarbonate of.	S.	Carbonic Acid... Ammonia....... Water..........	2 1 1	44 17 9	70	
Baryta, Carbonate of	S.&A.	Carbonic Acid... Baryta..........	1 1	22 78	100	
Bismuth, Proto-tricarbonate of................	S.	Carbonic Acid... Protox. Bism.... Water..........	1 3 2	22 80 18	120	
Cadmium, Carbonate of...	S.&A.	Carbonic Acid... Protox. Cadm....	1 1	22 64	86	
Cobalt, Carbonate of	S.	Carbonic Acid... Protox. Cobalt... Water..........	1 1 1	22 34 9	65	
Copper, Proto-dicarbonate of................	S.	Carbonic Acid... Protox. Copper.. Water..........	1 2 1	22 80 9	111	
Ditto, Ditto............	A.	Carbonic Acid... Protox. Copper..	1 2	22 80	102	
Iron, Proto-carbonate o ..	A.	Carbonic Acid... Protox. Iron.....	1 1	22 36	58	
Lead, Proto-carbonate of.	A.	Carbonic Acid... Protox. Lead....	1 1	22 112	134	

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions by Weight	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Lime, Carbonate of......	A.	Carbonic Acid... Lime...........	1 1	22 28	50	
Magnesia, Carbonate of ..	S.	Carbonic Acid... Magnesia....... Water..........	1 1 3	22 20 27	69	
Ditto, Ditto............	A.	Carbonic Acid... Magnesia.......	1 1	22 20	42	
Manganese, Proto-carbonate of................	S.	Carbonic Acid... Protox. Mang.... Water..........	1 1 2	22 36 18	76	
Mercury, Prot-hemibicarbonate of (Sesquicarbonate)..................	A.	Carbonic Acid... Protox. Merc.....	1½ 1	33 208	241	
Nickel, Proto-carbonate of	S.	Carbonic Acid... Protox. Nickel... Water..........	1 1 3	22 34 27	83	
Potassa, Carbonate of....	C.	Carbonic Acid... Potassa......... Water..........	1 1 2	22 48 18	88	
Ditto, Prot-hemi-bicarbonate of, (Sesquicarbonate)..................	C.	Carbonic Acid... Potassa......... Water..........	1½ 1 6	33 48 54	135	
Potassium, Proto-bicarbonate of................	C.	Carbonic Acid... Potassa......... Water..........	2 1 1	44 48 9	101	
Silver, Proto-carbonate of.	..	Carbonic Acid... Protox. Silver...	1 1	22 118	140	
Sodium, Proto-carbonate of	C.	Carbonic Acid... Soda........... Water..........	1 1 10	22 32 90	144	
Ditto, Prot-hemi-bicarbonate of, (Sesquicarbonate)	C.	Carbonic Acid... Soda........... Water..........	1½ 1 2	33 32 18	83	
Ditto, Bicarbonate of.....	C.	Carbonic Acid... Soda........... Water..........	2 1 1	44 32 9	85	
Strontia, Proto-carbonate of................	A.	Carbonic Acid... Strontia.........	1 1	22 52	74	
Uranium, Deuto-carbonate of................	..	Carbonic Acid... Deutox. Uran.... Water..........	1 1 1	22 224 9	255	
Yttrium, Proto-carbonate of................	..	Carbonic Acid... Yttria........... Water..........	1 1 1	22 42 9	73	
Zinc, Proto-carbonate of..	C.	Carbonic Acid... Protox. Zinc..... Water..........	1 1 1	22 42 9	73	
Ditto, Ditto............	A.	Carbonic Acid... Protox. Zinc.....	1 1	22 42	64	
Cathartin...............	..		..	..	..	[illegible]
Carmine...............	..		..	..	..	[illegible]
Carthamine...............	..		..	..	..	[illegible]
Cerebral substance........	..		..	..	..	[illegible]
Cerine...............	..		..	..	..	[illegible]
Cerium...............	S.		..	..	50	[illegible]
Charcoal...............	S.		..	..	..	[illegible]
Cheese...............	..		..	..	..	[illegible]
Chlorates...............	..		..	..	..	[illegible]
Baryum, Proto-chlorate of	A.	Chloric Acid.... Baryta..........	1 1	76 78	154	
Lead, Proto-chlorate of...	A.	Chloric Acid.... Protox. Lead....	1 1	76 112	188	
Mercury, Proto-chlorate of	A.	Chloric Acid.... Protox. Merc....	1 1	76 208	284	
Potassium, Proto-chlorate of................	A.	Chloric Acid.... Potassa.........	1 1	76 48	124	
Chlorides...............	..		..	..	..	[illegible]
Antimony, Chloride of....	..	Chlorine........ Antimony.......	1 1	36 44	80	
Ditto, Dichloride of	..	Chlorine........ Antimony.......	1 2	36 88	124	
Baryum, Chloride of	..	Chlorine........ Baryum.........	1 1	36 70	106	
Bismuth, Chloride of	..	Chlorine........ Bismuth.........	1 1	36 72	108	
Cadmium, Chloride of	..	Chlorine........ Cadmium.......	1 1	36 56	92	
Cerium, Chloride of......	..	Chlorine........ Cerium..........	1 1	36 50	86	
Chromium, Chloride of ...	..	Chlorine........ Chromium.......	1 1	36 28	64	
Cobalt, Chloride of.......	..	Chlorine........ Cobalt...........	1 1	36 26	62	

TABLE XII. *continued.*

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions, by Weight.	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Copper, Chloride of	S.	Chlorine Copper	1 1	36 32	68	
Ditto, Dichloride of	S.	Chlorine Copper	1 2	36 64	100	
Glycynum, Chloride of	S.	Chlorine Glycynum	1 1	36 18	54	
Gold, Chloride of	..	Chlorine Gold	1 1	36 200	236	
Ditto, Bichloride of	..	Chlorine Gold	2 1	72 200	272	
Iron, Chloride of	..	Chlorine Iron	1 1	36 28	64	
Ditto, Semi-bichloride of (Sesquichloride)	..	Chlorine Iron	1½ 1	54 28	82	
Lead, Chloride of	..	Chlorine Lead	1 1	36 104	140	
Lime, Chloride of	..	Chlorine Lime	1 1	36 20	56	
Lithium, Chloride of	..	Chlorine Lithium	1 1	36 10	46	
Magnesium, Chloride of	..	Chlorine Magnesium	1 1	36 12	48	
Manganese, Chloride of	..	Chlorine Manganese	1 1	36 28	64	
Mercury, Chloride of (Calomel)	..	Chlorine Mercury	1 1	36 200	236	
Ditto, Bichloride of (Corrosive Sublimate)	..	Chlorine Mercury	2 1	72 200	272	
Nickel, Chloride of	..	Chlorine Nickel	1 1	36 26	62	
Palladium, Chloride of	..	Chlorine Palladium	1 1	36 56	92	
Platinum, Chloride of	..	Chlorine Platinum	1 1	36 96	132	
Ditto, Bichloride of	..	Chlorine Platinum	2 1	72 96	168	
Potassium, Chloride of	..	Chlorine Potassium	1 1	36 40	76	
Rhodium, Chloride of	..	Chlorine Rhodium	1 1	36 44	80	
Silver, Chloride of	..	Chlorine Silver	1 1	36 110	146	
Sodium, Chloride of	..	Chlorine Sodium	1 1	36 24	60	
Strontium, Chloride of	..	Chlorine Strontium	1 1	36 44	80	
Tin, Chloride of	..	Chlorine Tin	1 1	36 58	94	
Ditto, Bichloride of	..	Chlorine Tin	2 1	72 58	130	
Uranium, Chloride of	..	Chlorine Uranium	1 1	36 208	244	
Yttrium, Chloride of	..	Chlorine Yttrium	1 1	36 34	70	
Zinc, Chloride of	..	Chlorine Zinc	1 1	36 34	70	
Zirconium, Chloride of	..	Chlorine Zirconia	1 1	36 40	76	
Chlorine	G.		..	..	36	(133)
Chromates	..		..	..	..	(783)
Ammonia, Chromate of	A.	Chromic Acid Ammonia	1 1	52 17	69	
Ditto, Bichromate of	C.	Chromic Acid Ammonia Water	2 1 2	104 17 18	139	
Baryta, Chromate of	A.	Chromic Acid Baryta	1 1	52 78	130	
Bismuth, Chromate of	..	Chromic Acid Oxide of Bism. Water	1 1 2	52 80 18	150	
Cadmium, Chromate of	..	Chromic Acid Ox. of Cadm. Water	1 1 5	52 64 45	161	
Chromium, Chromate of	..	Chromic Acid Ox. of Chromium	1 1	52 36	88	
Cobalt, Chromate of	..	Chromic Acid Ox. of Cobalt Water	1 1 2	52 34 18	104	
Copper, Proto-chromate of	..	Chromic Acid Protox. Copper. Water	1 1 2	52 40 18	110	
Lead, Proto-chromate of	A.	Chromic Acid Protox. Lead	1 1	52 112	164	
Lime, Chromate of	A.	Chromic Acid Lime	1 1	52 28	80	
Magnesia, Chromate of	..	Chromic Acid Magnesia Water.	1 1 2	52 20 18	90	
Mercury, Proto-chromate of	A.	Chromic Acid Protox. Merc.	1 1	52 208	260	
Nickel, Proto-chromate of	..	Chromic Acid Protox. Nickel. Water	1 1 4	52 34 36	122	
Potassa, Chromate of	A.	Chromic Acid Potassa.	1 1	52 48	100	
Ditto, Bichromate of	A.	Chromic Acid Potassa.	2 1	104 48	152	
Silver, Chromate of	A.	Chromic Acid Oxide of Silver	1 1	52 118	170	
Soda, Chromate of	..	Chromic Acid Soda Water	1 1 12	52 32 108	192	
Strontia, Chromate of	A.	Chromic Acid Strontia	1 1	52 52	104	
Zinc, Chromate of	..	Chromic Acid Oxide of Zinc	1 1	52 42	94	
Chromium	S.		..	..	28	(722)
Chyle	L.		..	..	..	(1093)
Chyme	L.		..	..	..	(1092)
Cinchonine	S.		..	..	..	(1004)
Coal	S.		..	..	..	(1025)
Coal Gas	G.		..	..	..	(323)
Cobalt	S.		..	..	26	(787)
Columbates	..		..	..	..	(753)
Soda, Columbate of	..	Columbic Acid Soda Water	1 1 10	152 32 90	274	
Colocynthin	S.		..	..	..	(1060)
Columbium	S.		..	..	144	(745)
Copal	S.		..	..	..	(1017)
Copper	S.		..	..	32	(822)
Cytisine	S.		..	..	..	(1046)
Cyanogen	G.	Nitrogen Gas Carbon Vapour	1 2	14 12	26	(472)
Delphinia	S.		..	..	..	(1010)
Diabetic Sugar	S.		..	..	..	(1026)
Diamond	S.		..	..	..	(297)
Elaine	..		..	..	..	(1014)
Ellagic Acid	..		..	..	..	(985)
Emetine	S.		..	..	..	(1006)
Essential Oils	L.		..	..	..	(1016)
Ether, (see Æther)	L.		..	..	..	(1024)
Euchlorine (Protox. of Chlorine)	G.		..	..	..	(144)
Extractive	S.		..	..	..	(1047)
Fæces	..		..	..	..	(1097)
Fermentation	..		..	..	..	(106[illegible])
Ferro-chyazic Acid (Ferro-hydrocyanic A.)	..		..	..	..	(447)
Ferro-hydrocyanic Acid (see Acids)	..		..	..	..	(Do)
Ferro-prussic Acid (Ferro-hydrocyanic A.)	..		..	..	..	(Do.)
Fibrin	..		..	..	..	(1065)
Fluoborates (see Borofluates)	..		..	..	..	(191)
Fluorine	..		..	..	18?	(162)
Fluorides	..		..	..	..	(Do.)
Fluo-silicates (see Silicofluates)	..		..	..	..	(184)
Fulminating Mercury	..		..	..	..	(890)
Fungin	S.		..	..	..	(1048)
Gall Stones	S.		..	..	..	(1114)
Gastric Juice	L.		..	..	..	(1090)
Gelatine	..		..	..	..	(1067)
Gliadine	..		..	..	..	(1038)
Glycyna (Glucina)	S.		..	..	26	(508)
Glycynum	S.		..	..	18	(507)
Gluten	S.		..	..	..	(1038)
Gold	S.		..	..	200	(951)
Gum	S.		..	..	..	(1031)
Gum resins	S.		..	..	..	(1018)
Hair	S.		..	..	..	(1101)
Hæmatine	S.		..	..	..	(1033)
Hordein	S.		..	..	..	(1051)
Horn	S.		..	..	..	(1102)
Hydriodates	..		..	..	..	(244)
Hydrochloric Acid, see Acids. (Muriatic Acid.)	..		..	..	..	(149)
Hydrochlorates.						
Alumina, H. of	..	HydrochloricAcid Alumina Water	1 1 3	37 27 27	91	
Ammonia, H. of (Sal Ammoniac)	A.	HydrochloricAcid Ammonia	1 1	37 17	54	
Baryta, H. of	C.	HydrochloricAcid Baryta Water	1 1 1	37 78 9	124	
Bismuth, H. of	C.	HydrochloricAcid Oxide of Bism. Water	1 1 ?	37 80 ?	?	

TABLE XII. *continued.*

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions by Weight	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Cadmium, H. of	C.	HydrochloricAcid	1	37	110	
		Oxide of Cadm.	1	64		
		Water	1	9		
Cerium, H. of	C.	HydrochloricAcid	1	37	?	
		Oxide of Cerium.	1	58		
		Water	?	?		
Chromium, H. of.	C.	HydrochloricAcid	1	37	154	
		Oxide of Chrom.	1	36		
		Water	9	81		
Cobalt, Prot. H. of	C.	HydrochloricAcid	1	37	107	
		Protox. Cobalt	1	34		
		Water	4	36		
Copper, Prot. H. of	C.	HydrochloricAcid	1	37	95	
		Protox. Copper	1	40		
		Water	2	18		
Glycyna, H. of	C	HydrochloricAcid	1	37	?	
		Glycyna	1	26		
		Water	?	?		
Iron, Prot. H. of	C.	HydrochloricAcid	1	37	100	
		Protox. Iron	1	36		
		Water	3	27		
Lime, H. of.	C.	HydrochloricAcid	1	37	119	
		Lime	1	28		
		Water	6	54		
Lithia, H. of	C.	HydrochloricAcid	1	37	?	
		Lithia	1	18		
		Water	?	?		
Magnesia, H. of	C.	HydrochloricAcid	1	37	110	
		Magnesia	1	28		
		Water	5	45		
Manganese, Prot. H. of	C.	HydrochloricAcid	1	37	109	
		Protox. Mang.	1	36		
		Water	4	36		
Nickel, Prot. H. of	C.	HydrochloricAcid	1	37	116	
		Protox. Nickel	1	34		
		Water	5	45		
Strontia, H. of	C.	HydrochloricAcid	1	37	161	
		Strontia	1	52		
		Water	8	72		
Tin, Deuto-bihydrochl. of (Bimuriate of Tin)	C.	HydrochloricAcid	2	74	175	
		Deutox. of Tin	1	74		
		Water	3	27		
Zinc, Prot. Hydrochl. of	A.	HydrochloricAcid	1	37	79	
		Protox. Tin	1	42		
Zirconia, Hyd. of	C.	HydrochloricAcid	1	37	130	
		Zirconia	1	48		
		Water	5	45		
Hydrocyanates	..	....	..	..	..	(474)
Hydrofluates	..	....	..	..	..	(176)
Hydrogen	G.	....	..	..	1	(283)
Hydrogurets (Hydrurets)	..	....	..	..	..	(283)
Carbon, Hydrogurets of, see Art. (312.)	..	....	..	..	..	(312)
Phosphorus, Hydroguret of	..	Hydrogen	1	1	13	
		Phosphorus	1	12		
Ditto, Bihydroguret of.	..	Hydrogen	2	2	14	
		Phosphorus	1	12		
Hydruret of Sulphur (see Hydrosulphurous Acid.)	..	....	..	..	..	(403)
Hydrosulphates	..	....	..	..	..	(407)
Hypophosphites	..	....	..	..	..	(384)
Hyposulphates	..	....	..	..	..	(390)
Hyposulphites	..	....	..	..	..	(388)
Igasurates	..	....	..	..	..	(986)
Indigo	S.	....	..	..	..	(1035)
Inuline	S.	....	..	..	..	(1052)
Iodates	..	....	..	..	..	(226)
Iodine	S.	....	..	..	124	(207)
Iodides (Iodures)	..	....	..	..	..	(207)
Iridium	..	....	..	..	30	(964)
Iron	..	....	..	..	28	(648)
Ittria (see Yttria)	..	....	..	..	..	(498)
Jelly	..	....	..	..	..	(1049)
Kinates	..	....	..	..	..	(987)
Lac	S.	....	..	..	..	(988)
Laccates	..	....	..	..	..	(988)
Lead	S.	....	..	..	104	(845)
Lime	S.	....	..	..	28	(551)
Lithia	S.	....	..	..	18	(588)
Lithium	S.	....	..	..	10	(587)
Lymph	L.	....	..	..	..	(1105)
Lupuline	S.	....	..	..	..	(1053)
Magnesia	S.	....	..	..	20	(527)
Magnesium	S.	....	..	..	12	(526)
Malates	..	....	..	..	..	(979)
Manganese	..	....	..	..	28	(637)
Margarates	..	....	..	..	..	(1084)
Meconates	..	....	..	..	..	(989)
Mercury	..	....	..	..	200	(870)
Molybdates	..	....	..	..	..	(721)
Molybdenum	..	....	..	..	48	(710)
Moroxylates	..	....	..	..	..	(991)
Morphia	..	....	..	..	..	(1003)
Mucilage	..	....	..	..	..	(1031)
Mucates	..	....	..	..	..	(998)
Mucus	..	....	..	..	..	(1110)
Muriates (see Hydrochlorates)	..	....	..	..	..	(158)
Muriatic Acid (see Hydrochloric A.)	..	....	..	..	..	(149)
Nails	..	....	..	..	..	(1102)
Nanceic Acid	..	....	..	..	..	(999)
Naphtha	..	....	..	..	..	(1025)
Natron (see Carb. Soda)	..	....	..	..	..	(605)
Nickel	..	....	..	..	26	(883)
Nitrates	..	....	..	..	..	(458)
Alumina, Dinitrate of	..	Nitric Acid	1	54	180	
		Alumina	2	36		
		Water	10	90		
Ditto, Trinitrate of	..	Nitric Acid	1	54	162	
		Alumina	3	54		
		Water	6	54		
Ammonia, Nitrate of	..	Nitric Acid	1	54	80	
		Ammonia	1	17		
		Water	1	9		
Baryta, Nitrate of	..	Nitric Acid	1	54	132	
		Baryta	1	78		
Bismuth, Proto-nitrate of.	..	Nitric Acid	1	54	161	
		Protox. Bism.	1	80		
		Water	3	27		
Ditto, Proto-dinitrate of	..	Nitric Acid	1	54	232	
		Protox. Bism	2	160		
		Water	2	18		
Cadmium, Nitrate of	..	Nitric Acid	1	54	154	
		Oxide of.	1	64		
		Water	4	36		
Cobalt, Proto-nitrate of	..	Nitric Acid	1	54	142	
		Protox. Cobalt	1	34		
		Water	6	54		
Copper, Proto-nitrate of	..	Nitric Acid	1	54	157	
		Protox. Copper	1	40		
		Water	7	63		
Iron, Proto-nitrate of	..	Nitric Acid	1	54	153	
		Protox. Iron	1	36		
		Water	7	63		
Ditto, Hemideuto-semi binitrate of (Persesquinitrate)	..	Nitric Acid	1½	81	193	
		Hemideutox. Iron	1	40		
		Water	8	72		
Lead, Proto-nitrate of	C.&A.	Nitric Acid	1	54	166	
		Protox. Lead	1	112		
Lime, Nitrate of	C.	Nitric Acid	1	54	136	
		Lime	1	28		
		Water	6	54		
Magnesia, Nitrate of	C.	Nitric Acid	1	54	128	
		Magnesia	1	20		
		Water	6	54		
Manganese, Proto-nitrate of	..	Nitric Acid	1	54	153	
		Protox. Mang.	1	36		
		Water	7	63		
Mercury, Proto-nitrate of	..	Nitric Acid	1	54	280	
		Protox. Merc.	1	208		
		Water	2	18		
Ditto, Deuto-nitrate of (Pernitrate)	A.	Nitric Acid	1	54	270	
		Deutox. Merc.	1	216		
Nickel, Proto-nitrate of	..	Nitric Acid	1	54	133	
		Protox. Nick.	1	34		
		Water	5	45		
Potassa, Nitrate of (Nitre)	A.	Nitric Acid	1	54	102	
		Potassa	1	48		
Silver, Proto-nitrate of	A.	Nitric Acid	1	54	172	
		Protox. Silver	1	118		
Soda, Nitrate of	A.	Nitric Acid	1	54	86	
		Soda	1	32		
Strontia, Nitrate of	..	Nitric Acid	1	54	142	
		Strontia	1	52		
		Water	4	36		
Ditto, Ditto	A.	Nitric Acid	1	54	106	
		Strontia	1	52		

TABLE XII. *continued.*

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions by Weight	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Uranium, Deuto-semi-bi-nitrate of (Sesquinitrate)	..	Nitric Acid Deutox. of Uran. Water	1½ 1 17	81 224 153	458	
Zinc, Proto-nitrate of	..	Nitric Acid Protox. Zinc Water	1 1 6	54 42 54	150	
Nitric Æther	L.	....	..	..	..	(1024)
Nitrites	..	....	..	..	..	(455)
Nitrogen (Azote)	G.	....	..	..	14	(435)
Nitrous Gas	G.	....	..	..	..	(455)
Nitrous Oxide	G.	....	..	..	..	(451)
Oil	L.	....	..	..	..	(1015)
Olefiant Gas	G.	Carbon Hydrogen	2 2	12 2	14	(317)
Olivile	S.	....	..	..	..	(1055)
Osmium	S.	....	..	..	?	(895)
Oxalates	..	....	..	..	..	(980)
Oxides.						
Aluminum, Protox. of (Alumina)	S.	Oxygen Aluminum	1 1	8 10	18	(518)
Antimony, Protox. of	..	Oxygen Antimony	1 1	8 44	52	(757)
Ditto, Hemideutoxide of (Deutoxide, or Antimonious Acid)	..	Oxygen Antimony	1½ 1	12 44	56	(765)
Ditto, Deutoxide of (Peroxide, or Antimonic A.)	..	Oxygen Antimony	2 1	16 44	60	(766)
Arsenic, Deutoxide of (Arsenious Acid)	..	Oxygen Arsenic	2 1	16 38	54	(708)
Ditto, Tritoxide of (Arsenic Acid)	..	Oxygen Arsenic	3 1	24 38	62	(709)
Baryum, Protoxide of (Baryta)	S.	Oxygen Baryum	1 1	8 70	78	(575)
Ditto, Deutoxide of	..	Oxygen Baryum	2 1	16 70	86	
Bismuth, Protoxide of	..	Oxygen Bismuth	1 1	8 72	80	(813)
Cadmium, Protoxide of	..	Oxygen Cadmium	1 1	8 56	64	(687)
Calcium, Protoxide of (Lime)	..	Oxygen Calcium	1 1	8 20	28	(551)
Carbon, Protoxide of (Carbonic Oxide)	G.	Oxygen Carbon	1 1	8 6	14	(311)
Ditto, Deutoxide of (Carbonic Acid)	G.	Oxygen Carbon	2 1	16 6	22	(312)
Cerium, Protoxide of	..	Oxygen Cerium	1 1	8 50	58	(780)
Ditto, Hemideutoxide of (Peroxide)	..	Oxygen Cerium	1½ 1	12 50	62	(Do.)
Chlorine, Protoxide of (Euchlorine)	..	Oxygen Chlorine	1 1	8 36	44	(144)
Ditto, Tritoxide of ?	..	Oxygen Chlorine	3 1	24 36	60	(145)
Ditto, Tetartoxide of (Peroxide D.)	..	Oxygen Chlorine	4 1	32 36	68	(146)
Ditto, Pemptoxide of (Caloric Acid)	..	Oxygen Chlorine	5 1	40 36	76	(147)
Ditto, Heptoxide of (Perchloric Acid)	..	Oxygen Chlorine	7 1	56 36	92	(148)
Chromium, Protoxide of	..	Oxygen Chromium	1 1	8 28	36	(725)
Ditto, Deutoxide of	..	Oxygen Chromium	2 1	16 28	44	(Do.)
Ditto, Tritoxide of (Chromic Acid)	..	Oxygen Chromium	3 1	24 28	52	(733)
Cobalt, Protoxide of	..	Oxygen Cobalt	1 1	8 26	34	(790)
Ditto, Hemideutoxide of	..	Oxygen Cobalt	1½ 1	12 26	38	(Do.)
Columbium, Protoxide of (Columbic Acid)	..	Oxygen Columbium	1 1	8 144	152	(753)
Copper, Suboxide of (Red Oxide)	..	Oxygen Copper	1 2	8 64	72	(825)
Copper, Protoxide of (Black Oxide)	..	Oxygen Copper	1 1	8 32	40	(825)
Glycynum, Protoxide of	..	Oxygen Glycynum	1 1	8 18	26	(508)
Gold, Protoxide of	..	Oxygen Gold	1 1	8 200	208	(954)
Ditto, Tritoxide of	..	Oxygen Gold	3 1	24 200	224	(Do.)
Iron, Protoxide of	..	Oxygen Iron	1 1	8 28	36	(651)
Ditto, Hemideutoxide of (Peroxide)	..	Oxygen Iron	1½ 1	12 28	40	(Do.)
Lead, Protoxide of	S.	Oxygen Lead	1 1	8 104	112	(848)
Ditto, Hemideutoxide of (Deutoxide of L.)	S.	Oxygen Lead	1½ 1	12 104	116	(Do.)
Ditto, Deutoxide of (Peroxide of L.)	S.	Oxygen Lead	2 1	16 104	120	(Do.)
Lithium, Protoxide of (Lithia)	S.	Oxygen Lithium	1 1	8 10	18	(588)
Magnesium, Oxide of (Magnesia)	S.	Oxygen Magnesium	1 1	8 12	20	(527)
Manganese, Suboxide of	S.	Oxygen Manganese	1 2	8 56	64	(640)
Ditto, Protoxide of (Oxide of M.)	S.	Oxygen Manganese	1 1	8 28	36	(Do.)
Ditto, Hemideutoxide of (Deutoxide of M.)	S.	Oxygen Manganese	1½ 1	12 28	40	(Do.)
Ditto, Deutoxide of (Tritoxide of M.)	S.	Oxygen Manganese	2 1	16 23	44	(Do.)
Ditto, Tritoxide of? (Manganesous Acid)	S.	Oxygen Manganese	3 1	24 28	52	(Do.)
Ditto, Tetartoxide of (Manganesic Acid.)	S.	Oxygen Manganese	4 1	32 28	60	(Do.)
Mercury, Protoxide of	S.	Oxygen Mercury	1 1	8 200	208	(873)
Ditto, Deutoxide of (Peroxide of M.)	S.	Oxygen Mercury	2 1	16 200	216	(Do.)
Molybdenum, Protoxide of	..	Oxygen Molybdenum	1 1	8 48	56	(713)
Ditto, Deutoxide of (Molybdous A.)	..	Oxygen Molybdenum	2 1	16 48	64	(720)
Ditto, Tritoxide of (Molybdic A.)	..	Oxygen Molybdenum	3 1	24 48	72	(721)
Nickel, Protoxide of	..	Oxygen Nickel	1 1	8 26	34	(886)
Ditto, Hemideutoxide of	..	Oxygen Nickel	1½ 1	12 26	38	(Do.)
Nitrogen, Protoxide of (Nitrous Oxide)	G.	Oxygen Nitrogen	1 1	8 14	22	(451)
Ditto, Deutoxide of (Nitric Oxide)	G.	Oxygen Nitrogen	2 1	16 14	30	(455)
Ditto, Tritoxide of (Hyponitrous Acid.)	G.	Oxygen Nitrogen	3 1	24 14	38	(456)
Ditto, Tetartoxide of (Nitrous Acid)	G.	Oxygen Nitrogen	4 1	32 14	46	(457)
Ditto, Pemptoxide of (Nitric Acid.)	G.	Oxygen Nitrogen	5 1	40 14	54	(458)
Osmium	S.	....	..	..	?	(898)
Palladium, Protoxide of	S.	Oxygen Palladium	1 1	8 56	64	(920)
Platinum, Protoxide of	S.	Oxygen Platinum	1 1	8 96	104	(942)
Ditto, Deutoxide of (Peroxide of P.)	S.	Oxygen Platinum	2 1	16 96	112	(942)
Potassium, Protoxide of (Potassa)	S.	Oxygen Potassa	1 1	8 40	48	(625)
Ditto, Tritoxide of (Peroxide of P.)	S.	Oxygen Potassa	3 1	24 40	64	(617)
Rhodium, Protoxide of	S.	Oxygen Rhodium	1 1	8 44	52	(931)
Ditto, Deutoxide of (Peroxide of R.)	S.	Oxygen Rhodium	2 1	16 44	60	(Do.)

TABLE XII. *continued.*

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions of Weight	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Silver, Protoxide of	S.	Oxygen	1	8	118	(908)
		Silver	1	110		
Sodium, Protox. of (Soda)	S.	Oxygen	1	8	32	(605)
		Sodium	1	24		
Ditto, Hemideutoxide of (Peroxide of)	S.	Oxygen	1½	12	36	(600)
		Sodium	1	24		
Strontium, Protoxide of (Strontia)	S.	Oxygen	1	8	52	(563)
		Strontium	1	44		
Sulphur, Protoxide of (Hyposulphurous Acid)	..	Oxygen	1	8	24	(388)
		Sulphur	1	16		
Ditto, Deutoxide of (Sulphurous Acid)	G.	Oxygen	2	16	32	(389)
		Sulphur	1	16		
Ditto, Hemitritoxide of? (Hyposulphuric Acid)	..	Oxygen	2½	20	36	(390)
		Sulphur	1	16		
Ditto, Tritoxide of (Sulphuric Acid)	A.	Oxygen	3	24	40	(391)
		Sulphur	1	16		
Ditto, Ditto	L.	Dry Acid	1	40	49	(Do.)
		Water	1	9		
Tellurium, Protoxide of (Telluric Acid	..	Oxygen	1	8	40	(837)
		Tellurium	1	32		
Tin, Protoxide of	..	Oxygen	1	8	66	(663)
		Tin	1	58		
Ditto, Deutoxide of (Peroxide)	..	Oxygen	2	16	74	(Do.)
		Tin	1	58		
Titanium, Protoxide of	..	Oxygen	1	8	40	(801)
		Titanium	1	32		
Ditto, Deutoxide of (Titanic Acid)	..	Oxygen	2	16	48	(809)
		Titanium	1	32		
Tungsten, Deutoxide of (Brown oxide)	..	Oxygen	2	16	112	(737)
		Tungsten	1	96		
Ditto, Tritoxide of (Tungstic Acid)	..	Oxygen	3	24	120	(744)
		Tungsten	1	96		
Uranium, Protoxide of	..	Oxygen	1	8	216	(770)
		Uranium	1	208		
Ditto, Deutox. of (Perox.)	..	Oxygen	2	16	224	(776)
		Uranium	1	208		
Yttrium, Protoxide of (Yttria)	..	Oxygen	1	8	42	(499)
		Yttrium	1	34		
Zinc, Protoxide of	..	Oxygen	1	8	42	(675)
		Zinc	1	34		
Zirconium, Protoxide of (Zirconia)	..	Oxygen	1	8	48	(489)
		Zirconium	1	40		
Oxiodates (see Iodates)	..	....	..	..	..	(226)
Oxygen	..	....	..	..	8	(121)
Oxymuriates (see Chlorates)	..	....	..	..	..	(147)
Palladium	S.	....	..	..	56	(917)
Pancreatic juice	L.	....	..	..	..	(1089)
Pectic Acid	..	....	..	..	..	(992)
Piperine	S.	....	..	..	..	(1054)
Phosgene Gas (see Chlorocarbonic Acid Gas)	G.	....	..	..	..	(304)
Phosphates.						
Alumina, Phosphate of	..	Phosphoric Acid	1	28	73	
		Alumina	1	18		
		Water	3	27		
Ammonia, Phosphate of	..	Phosphoric Acid	1	28	63	
		Ammonia	1	17		
		Water	2	18		
Ditto, Biphosphate of	A.	Phosphoric Acid	2	56	73	
		Ammonia	1	17		
Baryta, Phosphate of	A.	Phosphoric Acid	1	28	106	
		Baryta	1	78		
Bismuth, Proto-phosph. of	..	Phosphoric Acid	1	28	135	
		Protox. Bism.	1	80		
		Water	3	27		
Cadmium, Proto-phosph. of	..	Phosphoric Acid	1	28	101	
		Protox. Cadm.	1	64		
		Water	1	9		
Cobalt, Proto-phosph. of	..	Phosphoric Acid	1	28	80	
		Protox. Cobalt	1	34		
		Water	2	18		
Copper, Proto-phosph. of	..	Phosphoric Acid	1	28	77	
		Protox. Copper	1	40		
		Water	1	9		
Ditto, Ditto, Ant.	A.	Phosphoric Acid	1	28	68	
		Protox. Copper	1	40		
Iron, Proto-phosph. of	..	Phosphoric Acid	1	28	91	
		Protox. Iron.	1	36		
		Water	3	27		

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions of Weight.	Total Weight of Atoms referred to Hyd.
Iron, Hemideuto-triphosph. of (Pertriphosph.)	..	Phosphoric Acid	1	28	[illegible]
		Hemi-deutox. Iron	3	120	
		Water	3	27	
Lead, Proto-phosph. of	A.	Phosphoric Acid	1	28	[illegible]
		Protox. Lead	1	112	
Lead, Proto-diphosphate of	A.	Phosphoric Acid	1	28	[illegible]
		Protox. Lead	2	224	
Lime, Phosphate of	A.	Phosphoric Acid	1	28	[illegible]
		Lime	1	28	
Ditto Semi-diphosphate of (Apatite)	A.	Phosphoric Acid	1	28	[illegible]
		Lime	1½	42	
Magnesia, Phosphate of	..	Phosphoric Acid	1	28	111
		Magnesia	1	20	
		Water	7	63	
Mercury, Proto-phosphate of	A.	Phosphoric Acid	1	28	[illegible]
		Protox. Merc.	1	208	
Nickel, Proto-phosphate of	..	Phosphoric Acid	1	28	[illegible]
		Protox. Nickel	1	34	
		Water	3	27	
Potassa, Phosphate of	..	Phosphoric Acid	1	28	85
		Potassa	1	48	
		Water	1	9	
Soda, Phosphate of	..	Phosphoric Acid	1	28	[illegible]
		Soda	1	32	
		Water	12	108	
Ditto, Biphosphate of	..	Phosphoric Acid	2	56	[illegible]
		Soda	1	32	
		Water	3½	31.5	
Strontia, Phosphate of	..	Phosphoric Acid	1	28	89
		Strontia	1	52	
		Water	1	9	
Ditto, Biphosphate of	..	Phosphoric Acid	2	56	126
		Strontia	1	52	
		Water	2	18	
Zinc, Phosphate of	..	Phosphoric Acid	1	28	88
		Protox. Zinc	1	42	
		Water	2	18	
Phosphites.					
Phosphorus	S.	....	..	..	12
Phosphurets.					
Phosphuretted Hydrogen (see Bihydroguret of Ph.)					
Picromel	..	....	..	..	..
Picrotoxine	..	....	..	..	..
Platinum	S.	....	..	..	96
Polychroite	..	....	..	..	..
Potassa (see Oxide of Potassium)	S.	....	..	..	48
Potassium	S.	....	..	..	40
Prussiates (see Hydrocyanates)					
Prussic Acid (see Hydrocyanic Acid)	..	....	..	..	..
Quicksilver (see Mercury)	L.	....	..	..	..
Quinine	S.	....	..	..	..
Quinic Acid	S.	....	..	..	..
Resins	S.	....	..	..	..
Rhodium	S.	....	..	..	44
Saclactates.					
Saliva	L.	....	..	..	..
Sarcocolle	S.	....	..	..	..
Seleniates	..	....	..	..	..
Selenion	S.	....	..	..	40
Seleniuretted Hydrogen (see Hydroselenic Acid).	..	....	..	..	..
Silica	..	Oxygen	1	8	16
		Silicon	1	8	
Silicon	S.	....	..	..	8
Silver	S.	....	..	..	110
Soda (see Oxide of Sodium)	S.	....	..	..	..
Solania	S.	....	..	..	..
Spirit of Wine (see Alcohol)	L.	....	..	..	..
Starch	S.	....	..	..	..
Strontia (see Oxide of Strontium)	S.	....	..	..	..
Strychnia	S.	....	..	..	..
Suberine	S.	....	..	..	..
Succinates	..	....	..	..	..
Sugar	S.	....	..	..	..
Sulphates.					
Alumina, Sulphate of	..	Sulphuric Acid	1	40	121
		Alumina	1	18	
		Water	7	63	
Ditto, Disulphate of	..	Sulphuric Acid	1	40	?
		Alumina	2	36	
		Water	?	?	

TABLE XII. *continued.*

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions by Weight	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Uranium, Deuto-semi-bi-nitrate of (Sesquinitrate)	..	Nitric Acid	1½	81	458	
		Deutox. of Uran.	1	224		
		Water	17	153		
Zinc, Proto-nitrate of	..	Nitric Acid	1	54	150	
		Protox. Zinc	1	42		
		Water	6	54		
Nitric Æther	L.		..	..	..	(1024)
Nitrites	..		..	..	..	(455)
Nitrogen (Azote)	G.		..	..	14	(435)
Nitrous Gas	G.		..	..	..	(455)
Nitrous Oxide	G.		..	..	..	(451)
Oil	L.		..	..	..	(1015)
Olefiant Gas	G.	Carbon	2	12	14	(317)
		Hydrogen	2	2		
Olivile	S.		..	..	..	(1055)
Osmium	S.		..	..	?	(895)
Oxalates	..		..	..	..	(980)
Oxides.						
Aluminum, Protox. of (Alumina)	S.	Oxygen	1	8	18	(518)
		Aluminum	1	10		
Antimony, Protox. of	..	Oxygen	1	8	52	(757)
		Antimony	1	44		
Ditto, Hemideutoxide of (Deutoxide, or Antimonious Acid)	..	Oxygen	1½	12	56	(765)
		Antimony	1	44		
Ditto, Deutoxide of (Peroxide, or Antimonic A.)	..	Oxygen	2	16	60	(766)
		Antimony	1	44		
Arsenic, Deutoxide of (Arsenious Acid)	..	Oxygen	2	16	54	(708)
		Arsenic	1	38		
Ditto, Tritoxide of (Arsenic Acid)	..	Oxygen	3	24	62	(709)
		Arsenic	1	38		
Barynm, Protoxide of (Baryta)	S.	Oxygen	1	8	78	(575)
		Barynm	1	70		
Ditto, Deutoxide of	..	Oxygen	2	16	86	
		Barynm	1	70		
Bismuth, Protoxide of	..	Oxygen	1	8	80	(813)
		Bismuth	1	72		
Cadmium, Protoxide of	..	Oxygen	1	8	64	(687)
		Cadmium	1	56		
Calcium, Protoxide of (Lime)	..	Oxygen	1	8	28	(551)
		Calcium	1	20		
Carbon, Protoxide of (Carbonic Oxide)	G.	Oxygen	1	8	14	(311)
		Carbon	1	6		
Ditto, Deutoxide of (Carbonic Acid)	G.	Oxygen	2	16	22	(312)
		Carbon	1	6		
Cerium, Protoxide of	..	Oxygen	1	8	58	(780)
		Cerium	1	50		
Ditto, Hemideutoxide of (Peroxide)	..	Oxygen	1½	12	62	(Do.)
		Cerium	1	50		
Chlorine, Protoxide of (Euchlorine)	..	Oxygen	1	8	44	(144)
		Chlorine	1	36		
Ditto, Tritoxide of ?	..	Oxygen	3	24	60	(145)
		Chlorine	1	36		
Ditto, Tetartoxide of (Peroxide D.)	..	Oxygen	4	32	68	(146)
		Chlorine	1	36		
Ditto, Pemptoxide of (Chloric Acid)	..	Oxygen	5	40	76	(147)
		Chlorine	1	36		
Ditto, Heptoxide of (Perchloric Acid)	..	Oxygen	7	56	92	(148)
		Chlorine	1	36		
Chromium, Protoxide of	..	Oxygen	1	8	36	(725)
		Chromium	1	28		
Ditto, Deutoxide of	..	Oxygen	2	16	44	(Do.)
		Chromium	1	28		
Ditto, Tritoxide of (Chromic Acid)	..	Oxygen	3	24	52	(733)
		Chromium	1	28		
Cobalt, Protoxide of	..	Oxygen	1	8	34	(790)
		Cobalt	1	26		
Ditto, Hemideutoxide of	..	Oxygen	1½	12	38	(Do.)
		Cobalt	1	26		
Columbium, Protoxide of (Columbic Acid)	..	Oxygen	1	8	152	(753)
		Columbium	1	144		
Copper, Suboxide of (Red Oxide)	..	Oxygen	1	8	72	(825)
		Copper	2	64		
Copper, Protoxide of (Black Oxide)	..	Oxygen	1	8	40	(825)
		Copper	1	32		
Glycynum, Protoxide of	..	Oxygen	1	8	26	(508)
		Glycynum	1	18		
Gold, Protoxide of	..	Oxygen	1	8	208	(954)
		Gold	1	200		
Ditto, Tritoxide of	..	Oxygen	3	24	224	(Do.)
		Gold	1	200		
Iron, Protoxide of	..	Oxygen	1	8	36	(651)
		Iron	1	28		
Ditto, Hemideutoxide of (Peroxide)	..	Oxygen	1½	12	40	(Do.)
		Iron	1	28		
Lead, Protoxide of	S.	Oxygen	1	8	112	(848)
		Lead	1	104		
Ditto, Hemideutoxide of (Deutoxide of L.)	S.	Oxygen	1½	12	116	(Do.)
		Lead	1	104		
Ditto, Deutoxide of (Peroxide of L.)	S.	Oxygen	2	16	120	(Do.)
		Lead	1	104		
Lithium, Protoxide of (Lithia)	S.	Oxygen	1	8	18	(588)
		Lithium	1	10		
Magnesium, Oxide of (Magnesia)	S.	Oxygen	1	8	20	(527)
		Magnesium	1	12		
Manganese, Suboxide of	S.	Oxygen	1	8	64	(640)
		Manganese	2	56		
Ditto, Protoxide of (Oxide of M.)	S.	Oxygen	1	8	36	(Do.)
		Manganese	1	28		
Ditto, Hemideutoxide of (Deutoxide of M.)	S.	Oxygen	1½	12	40	(Do.)
		Manganese	1	23		
Ditto, Deutoxide of (Tritoxide of M.)	S.	Oxygen	2	16	44	(Do.)
		Manganese	1	23		
Ditto, Tritoxide of ? (Manganesous Acid)	S.	Oxygen	3	24	52	(Do.)
		Manganese	1	28		
Ditto, Tetartoxide of (Manganesic Acid.)	S.	Oxygen	4	32	60	(Do.)
		Manganese	1	28		
Mercury, Protoxide of	S.	Oxygen	1	8	208	(873)
		Mercury	1	200		
Ditto, Deutoxide of (Peroxide of M.)	S.	Oxygen	2	16	216	(Do.)
		Mercury	1	200		
Molybdenum, Protoxide of	..	Oxygen	1	8	56	(713)
		Molybdenum	1	48		
Ditto, Deutoxide of (Molybdous A.)	..	Oxygen	2	16	64	(720)
		Molybdenum	1	48		
Ditto, Tritoxide of (Molybdic A.)	..	Oxygen	3	24	72	(721)
		Molybdenum	1	48		
Nickel, Protoxide of	..	Oxygen	1	8	34	(886)
		Nickel	1	26		
Ditto, Hemideutoxide of	..	Oxygen	1½	12	38	(Do.)
		Nickel	1	26		
Nitrogen, Protoxide of (Nitrous Oxide)	G.	Oxygen	1	8	22	(451)
		Nitrogen	1	14		
Ditto, Deutoxide of (Nitric Oxide)	G.	Oxygen	2	16	30	(455)
		Nitrogen	1	14		
Ditto, Tritoxide of (Hyponitrous Acid.)	G.	Oxygen	3	24	38	(456)
		Nitrogen	1	14		
Ditto, Tetartoxide of (Nitrous Acid)	G.	Oxygen	4	32	46	(457)
		Nitrogen	1	14		
Ditto, Pemptoxide of (Nitric Acid.)	G.	Oxygen	5	40	54	(458)
		Nitrogen	1	14		
Osmium	S.		..	..	?	(898)
Palladium, Protoxide of	S.	Oxygen	1	8	64	(920)
		Palladium	1	56		
Platinum, Protoxide of	S.	Oxygen	1	8	104	(942)
		Platinum	1	96		
Ditto, Deutoxide of (Peroxide of P.)	S.	Oxygen	2	16	112	(942)
		Platinum	1	96		
Potassium, Protoxide of (Potassa)	S.	Oxygen	1	8	48	(625)
		Potassa	1	40		
Ditto, Tritoxide of (Peroxide of P.)	S.	Oxygen	3	24	64	(617)
		Potassa	1	40		
Rhodium, Protoxide of	S.	Oxygen	1	8	52	(931)
		Rhodium	1	44		
Ditto, Deutoxide of (Peroxide of R.)	S.	Oxygen	2	16	60	(Do.)
		Rhodium	1	44		

TABLE XII. *continued.*

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions of Weight	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Silver, Protoxide of	S.	Oxygen Silver	1 1	8 110	118	(908)
Sodium, Protox. of (Soda)	S.	Oxygen Sodium	1 1	8 24	32	(605)
Ditto, Hemideutoxide of (Peroxide of)	S.	Oxygen Sodium	1½ 1	12 24	36	(600)
Strontium, Protoxide of (Strontia)	S.	Oxygen Strontium	1 1	8 44	52	(563)
Sulphur, Protoxide of (Hyposulphurous Acid)	..	Oxygen Sulphur	1 1	8 16	24	(388)
Ditto, Deutoxide of (Sulphurous Acid)	G.	Oxygen Sulphur	2 1	16 16	32	(389)
Ditto, Hemitritoxide of? (Hyposulphuric Acid)	..	Oxygen Sulphur	2½ 1	20 16	36	(390)
Ditto, Tritoxide of (Sulphuric Acid)	A.	Oxygen Sulphur	3 1	24 16	40	(391)
Ditto, Ditto	L.	Dry Acid Water	1 1	40 9	49	(Do.)
Tellurium, Protoxide of (Telluric Acid	..	Oxygen Tellurium	1 1	8 32	40	(837)
Tin, Protoxide of	..	Oxygen Tin	1 1	8 58	66	(663)
Ditto, Deutoxide of (Peroxide)	..	Oxygen Tin	2 1	16 58	74	(Do.)
Titanium, Protoxide of	..	Oxygen Titanium	1 1	8 32	40	(801)
Ditto, Deutoxide of (Titanic Acid)	..	Oxygen Titanium	2 1	16 32	48	(809)
Tungsten, Deutoxide of (Brown oxide)	..	Oxygen Tungsten	2 1	16 96	112	(737)
Ditto, Tritoxide of (Tungstic Acid)	..	Oxygen Tungsten	3 1	24 96	120	(744)
Uranium, Protoxide of	..	Oxygen Uranium	1 1	8 208	216	(770)
Ditto, Deutox. of (Perox.)	..	Oxygen Uranium	2 1	16 208	224	(776)
Yttrium, Protoxide of (Yttria)	..	Oxygen Yttrium	1 1	8 34	42	(499)
Zinc, Protoxide of	..	Oxygen Zinc	1 1	8 34	42	(675)
Zirconium, Protoxide of (Zirconia)	..	Oxygen Zirconium	1 1	8 40	48	(489)
Oxiodates (see Iodates)	..	....	..	..	..	(226)
Oxygen	..	....	..	..	8	(121)
Oxymuriates (see Chlorates)	..	....	..	..	..	(147)
Palladium	S.	....	..	..	56	(917)
Pancreatic juice	L.	....	..	..	..	(1089)
Pectic Acid	..	....	..	..	..	(992)
Piperine	S.	....	..	..	..	(1054)
Phosgene Gas (see Chlorocarbonic Acid Gas)	G.	....	..	..	..	(304)
Phosphates.						
Alumina, Phosphate of	..	Phosphoric Acid Alumina Water	1 1 3	28 18 27	73	
Ammonia, Phosphate of	..	Phosphoric Acid Ammonia Water	1 1 2	28 17 18	63	
Ditto, Biphosphate of	A.	Phosphoric Acid Ammonia	2 1	56 17	73	
Baryta, Phosphate of	A.	Phosphoric Acid Baryta	1 1	28 78	106	
Bismuth, Proto-phosph. of	..	Phosphoric Acid Protox. Bism. Water	1 1 3	28 80 27	135	
Cadmium, Proto-phosph. of	..	Phosphoric Acid Protox. Cadm. Water	1 1 1	28 64 9	101	
Cobalt, Proto-phosph. of	..	Phosphoric Acid Protox. Cobalt Water	1 1 2	28 34 18	80	
Copper, Proto-phosph. of	..	Phosphoric Acid Protox. Copper Water	1 1 1	28 40 9	77	
Ditto, Ditto, Ant.	A.	Phosphoric Acid Protox. Copper	1 1	28 40	68	
Iron, Proto-phosph. of	..	Phosphoric Acid Protox. Iron Water	1 1 3	28 36 27	91	
Iron, Hemideuto-triphosph. of (Pertriphosph.)	..	Phosphoric Acid Hemi-deutox. Iron Water	1 3 3	28 120 27	175	
Lead, Proto-phosph. of	A.	Phosphoric Acid Protox. Lead	1 1	28 112	140	
Lead, Proto-diphosphate of	A.	Phosphoric Acid Protox. Lead	1 2	28 224	252	
Lime, Phosphate of	A.	Phosphoric Acid Lime	1 1	28 28	56	
Ditto Semi-diphosphate of (Apatite)	A.	Phosphoric Acid Lime	1 1½	28 42	70	
Magnesia, Phosphate of	..	Phosphoric Acid Magnesia Water	1 1 7	28 20 63	111	
Mercury, Proto-phosphate of	A.	Phosphoric Acid Protox. Merc.	1 1	28 208	236	
Nickel, Proto-phosphate of	..	Phosphoric Acid Protox. Nickel Water	1 1 3	28 34 27	89	
Potassa, Phosphate of	..	Phosphoric Acid Potassa Water	1 1 1	28 48 9	85	
Soda, Phosphate of	..	Phosphoric Acid Soda Water	1 1 12	28 32 108	168	
Ditto, Biphosphate of	..	Phosphoric Acid Soda Water	2 1 3½	56 32 31.5	119.5	
Strontia, Phosphate of	..	Phosphoric Acid Strontia Water	1 1 1	28 52 9	89	
Ditto, Biphosphate of	..	Phosphoric Acid Strontia Water	2 1 2	56 52 18	126	
Zinc, Phosphate of	..	Phosphoric Acid Protox. Zinc Water	1 1 2	28 42 18	88	
Phosphites.						
Phosphorus	S.	....	..	..	12	(346)
Phosphurets.						
Phosphuretted Hydrogen (see Bihydroguret of Ph.)						
Picromel	..	....	..	..	..	(1079)
Picrotoxine	..	....	..	..	..	(1011)
Platinum	S.	....	..	..	96	(929)
Polychroite	..	....	..	..	..	(1036)
Potassa (see Oxide of Potassium)	S.	....	..	..	48	(615)
Potassium	S.	....	..	..	40	(614)
Prussiates (see Hydrocyanates)						
Prussic Acid (see Hydrocyanic Acid)	..	....	..	..	..	(474)
Quicksilver (see Mercury)	L.	....	..	..	..	(870)
Quinine	S.	....	..	..	..	(1005)
Quinic Acid	S.	....	..	..	..	(997)
Resins	S.	....	..	..	..	(1017)
Rhodium	S.	....	..	..	44	(928)
Saclactates.						
Saliva	L.	....	..	..	..	(1089)
Sarcocolle	S.	....	..	..	..	(1056)
Seleniates	..	....	..	..	..	(427)
Selenion	S.	....	..	..	40	(409)
Seleniuretted Hydrogen (see Hydroselenic Acid)	..	....	..	..	..	(422)
Silica	..	Oxygen Silicon	1 1	8 8	16	(371)
Silicon	S.	....	..	..	8	(351)
Silver	S.	....	..	..	110	(905)
Soda (see Oxide of Sodium)	S.	....	..	..	..	(605)
Solania	S.	....	..	..	..	(1012)
Spirit of Wine (see Alcohol)	L.	....	..	..	..	(1023)
Starch	S.	....	..	..	..	(1030)
Strontia (see Oxide of Strontium)	S.	....	..	..	..	(563)
Strychnia	S.	....	..	..	..	(1007)
Suberine	S.	....	..	..	..	(1037)
Succinates	..	....	..	..	..	(996)
Sugar	S.	....	..	..	..	(1036)
Sulphates.						
Alumina, Sulphate of	..	Sulphuric Acid Alumina Water	1 1 7	40 18 63	121	
Ditto, Disulphate of	..	Sulphuric Acid Alumina Water	1 2 ?	40 36 ?	?	

TABLE XII. *continued.*

stance.	State.	Elements.	No. of Atoms.	Constituent Proportions by Weight	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Trisulphate of..	..	Sulphuric Acid Alumina Water	1 3 9	40 54 81	175	
Sulphate of....	..	Sulphuric Acid Ammonia Water	1 1 1	40 17 9	66	
lphate of	A.&C.	Sulphuric Acid Baryta	1 1	40 78	118	
roto-sulph. of..	..	Sulphuric Acid Protox. Bism	1 1	40 80	120	
Proto-sulph. of.	C.	Sulphuric Acid Protox. Cadm. Water	1 1 4	40 64 36	140	
oto-sulph. of ..	..	Sulphuric Acid Protox. Cerium Water	1 1 3	40 58 27	125	
to-sulph. of....	..	Sulphuric Acid Protox. Cobalt Water	1 1 7	40 34 63	137	
-bisulph. of ...	..	Sulphuric Acid Protox. Cobalt Water	2 1 3	80 34 27	141	
oto-sulph. of...	..	Sulphuric Acid Protox. Copper Water	1 1 5	40 40 45	125	
isulph. of	..	Sulphuric Acid Glycyna Water	2 1 5	80 26 45	151	
sulph. of......	..	Sulphuric Acid Protox. Iron Water	1 1 7	40 36 63	139	
idento-semi-bi- Persesquisulph-)	..	Sulphuric Acid Hemideutox. Iron Water	1½ 1 ?	60 40 ?	?	
-sulph. of.....	..	Sulphuric Acid Protox. Lead	1 1	40 112	152	
. of (Selenite).	..	Sulphuric Acid Lime Water	1 1 2	40 28 18	86	
....	A.	Sulphuric Acid Lime	1 1	40 28	68	
h. of	..	Sulphuric Acid Lithia Water	1 1 1	40 18 9	67	
ulph. of (Epsom	..	Sulphuric Acid Magnesia Water	1 1 7	40 20 63	123	
Proto-sulph. of	C.	Sulphuric Acid Protox. Mangan. Water	1 1 5	40 36 45	121	
roto-sulph. of..	..	Sulphuric Acid Protox. Merc. Water	1 1 2	40 208 18	266	
-sulph. of.....	A.	Sulphuric Acid Deutox. Merc.	1 1	40 216	256	
to-sulph. of ...	..	Sulphuric Acid Protox. Nickel Water	1 1 7	40 34 63	137	
Deuto-sulph. of.	A.	Sulphuric Acid Deutox. Plat.	1 1	40 112	152	
lphate of......	C.&A.	Sulphuric Acid Potassa	1 1	40 48	88	
lphate of......	C.&H.	Sulphuric Acid Potassa Water	2 1 2	80 48 18	146	
tosulphate of ..	C.&A.	Sulphuric Acid Protox. Silver	1 1	40 118	158	
hate of (Glau- t)	C.&H.	Sulphuric Acid Soda Water	1 1 10	40 32 90	162	
lphate of	C.&A.	Sulphuric Acid Strontia	1 1	40 52	92	
euto-semi-bisul-	C.&H.	Sulphuric Acid Deutox. Uran. Water	1½ 1 4	60 224 36	320	
phate of	C.&H.	Sulphuric Acid Yttria Water	1 1 ?	40 42 ?	?	
-sulphate of ...	C.&H.	Sulphuric Acid Protox. Zinc Water	1 1 7	40 42 63	145	
....	S.	....	..	..	16	(376.)
lphuret of	..	Sulphur Arsenic	1 1	16 38	54	
i-bisulphuret of	..	Sulphur Arsenic	1½ 1	24 38	62	
Sulphuret of ..	..	Sulphur Antimony	1 1	16 44	60	

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions by Weight	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Baryum, Sulphuret of....	..	Sulphur Baryum	1 1	16 70	86	
Bismuth, Sulphuret of ...	..	Sulphur Bismuth	1 1	16 72	88	
Cadmium, Sulphuret of...	..	Sulphur Cadmium	1 1	16 56	72	
Calcium, Sulphuret of....	..	Sulphur Calcium	1 1	16 20	36	
Cerium, Sulphuret of.....	..	Sulphur Cerium	1 1	16 50	66 ?	
Chromium, Sulphuret of..	..	Sulphur Chromium	1 1	16 28	44	
Cobalt, Sulphuret of......	..	Sulphur Cobalt	1 1	16 26	42	
Columbium, Sulphuret of.	..	Sulphur Columbium	1 1	16 144	160	
Copper, Disulphuret of...	..	Sulphur Copper	1 2	16 64	80	
Ditto, Sulphuret of.......	..	Sulphur Copper	1 1	16 32	48	
Ditto, Bisulphuret of.....	..	Sulphur Copper	2 1	32 32	64	
Gold, Tersulphuret of	..	Sulphur Gold	3 1	48 200	248	
Iron, Sulphuret of........	..	Sulphur Iron	1 1	16 28	44	
Ditto, Semi-bisulphuret of (Sesquisulphuret)	..	Sulphur Iron	1½ 1	24 28	52	
Ditto, Bisulphuret of	..	Sulphur Iron	2 1	32 28	60	
Lead, Disulphuret of.....	..	Sulphur Lead	1 2	16 208	224	
Ditto, Sulphuret of.......	..	Sulphur Lead	1 1	16 104	120	
Ditto, Bisulphuret of.....	..	Sulphur Lead	2 1	32 104	136	
Lithium, Sulphuret of	..	Sulphur Lithium	1 1	16 10	26 ?	
Magnesium, Sulphuret of .	..	Sulphur Magnesium	1 1	16 12	28	
Manganese, Sulphuret of .	..	Sulphur Manganese	1 1	16 28	44	
Mercury, Sulphuret of ...	..	Sulphur Mercury	1 1	16 200	216	
Ditto, Bisulphuret of.....	..	Sulphur Mercury	2 1	32 200	232	
Nickel, Sulphuret of	..	Sulphur Nickel	1 1	16 26	42	
Palladium, Sulphuret of..	..	Sulphur Palladium	1 1	16 56	72	
Platinum, Sulphuret of...	..	Sulphur Platinum	1 1	16 96	112	
Ditto, Bisulphuret of.....	..	Sulphur Platinum	2 1	32 96	128	
Potassium, Sulphuret of..	..	Sulphur Potassium	1 1	16 40	56	
Ditto, Bisulphuret of.....	..	Sulphur Potassia	2 1	32 40	72	
Ditto, Tersulphuret of....	..	Sulphur Potassium	3 1	48 40	88	
Ditto, Quatersulphuret of.	..	Sulphur Potassium	4 1	64 40	104	
Ditto, Quintosulphuret of.	..	Sulphur Potassium	5 1	80 40	120	
Rhodium, Sulphuret of ...	..	Sulphur Rhodium	1 1	16 44	60	
Silver, Sulphuret of......	..	Sulphur Silver	1 1	16 110	126	
Sodium, Sulphuret of.....	..	Sulphur Sodium	1 1	16 24	40	
Strontium, Sulphuret of ..	..	Sulphur Strontium	1 1	16 44	60	
Tin, Sulphuret of	..	Sulphur Tin	1 1	16 58	74	
Ditto, Semi-bisulphuret of (Sesquisulphuret)	..	Sulphur Tin	1½ 1	24 58	82	
Ditto, Bisulphuret of	..	Sulphur Tin	2 1	32 58	90	
Titanium, Sulphuret of...	..	Sulphur Titanium	1 1	16 32	48	
Uranium, Sulphuret of ...	..	Sulphur Uranium	1 1	16 208	224	
Zinc, Sulphuret of	..	Sulphur Zinc	1 1	16 34	50	
Sulphuretted hydrogen (Hydrosulphuric Acid)						
Synovia	..	....	..	..	..	(1106)
Tannin	..	....	..	..	..	(1040)
Tartrates	..	....	..	..	..	(996)
Tellurets	..	....	..	..	..	(840)
Telluretted Hydrogen (Hydrotelluric Acid)						

TABLE XII. *continued.*

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions by Weight.	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Tellurium	S.	....	..	..	32	(834)
Thorina	S.	....	..	..	..	(516)
Thorinum	S.	....	..	..	..	(Do.)
Tin	S.	....	..	..	58	(660)
Titanium	S.	....	..	..	32	(798)
Tungstates.						
Tungsten	S.	....	..	..	126	(734
Turpentine	L.	....	..	..	..	(1016)
Ulmin	S.	....	..	..	..	(1058)
Uranium	S.	....	..	..	208	(767)
Urates	..	....	..	..	..	(1072)

Substance.	State.	Elements.	No. of Atoms.	Constituent Proportions by Weight.	Total Weight of Atoms referred to Hyd.	Article in this Treatise.
Urea	C.	....	..	..	..	(1069)
Urine	L.	....	..	..	..	(1075)
Veratria	C.	....	..	..	..	(1009)
Vinous fermentation	..	....	..	..	..	(1062)
Volatile Alkali (Ammonia)	G.	....	..	..	..	(460)
Water	L.	Hydrogen Oxygen	1 1	1 8	9	(295)
Yeast	L.	....	..	..	..	(1039)
Yttria	S.	....	..	..	..	(499)
Yttrium	S.	....	..	..	34	(498)
Zinc	S.	....	..	..	42	(672)
Zirconia	S.	....	..	..	48	(489)
Zirconium	S.	....	..	..	40	(488)

Note. From the use of descriptive names in this Table, it must not be inferred that these are designed in all cases to supersede those already in use: thus, for instance, among the Oxides, Pemptoxide of Nitrogen is placed in the first column to preserve the harmony of the system of nomenclature, and to inculcate a descriptive appellation; but the synonyme, Nitric Acid, is well established, and will doubtless continue in use.

In Art. (878.) an inaccuracy exists, the origin of which we cannot comprehend. The union of Selenion with Mercury should have been noticed under Art. (877.); whilst under (878.) I. it should have been stated that Mercury has generally a strong tendency to unite with other Metals; and that it refuses to do so in very few, and even these uncertain, cases.

In Art. (111.) the reader is requested to erase a paragraph of four lines, beginning "The definite," &c. at the ninth line from the end, as it has been found necessary to abandon that plan, and to confine the prefixes Prot-, Deut-, &c. to the oxides only.

SOUND.

PART I.

OF THE PROPAGATION OF SOUND IN GENERAL.

§ I. *Of the Propagation and Velocity of Sound in Air.*

Part I.

1. To explain the nature and production of Sound, the laws of its propagation through the various media which convey it to our ears, and the manner of its action on those organs; the modifications of which it is susceptible in speech, in music, or in inarticulate and unmeaning noises; and the means, natural or artificial, of producing, regulating, or estimating them, are the proper objects of Acoustics.

2. Sound is conveyed to us by means of the air. Every body knows that Sounds are conveyed to our ears from a distance through the air, but it is not equally apparent that they would not reach us as well through a space perfectly void; or, in other words, that the air itself is the vehicle, or active agent, by whose operation they are conveyed to us. Such, however, is the case. Shortly after the invention of the air-pump, it was found that the collision of hard bodies in an exhausted receiver produced no appreciable Sound. Hanksbee (*Philosophical Transactions*, 1705) having suspended a bell in the receiver of an air-pump, found the Sound die away by degrees, as the air was exhausted, and again increase on its readmission; and when made to sound in a vessel full of air, the Sound was not transmitted through the interval between that and an exterior vessel from which the air had been extracted, though it passed freely when readmitted. On the other hand, when the air was condensed in a receiver, the Sound of a suspended bell was stronger than in natural air, and its intensity increased with the degree of condensation. Roebuck, (*Transactions of the Royal Society, Edinburgh*, vol. v. p. 34,) when shut up in a cavity excavated in a rock, which served as a reservoir of air for an iron foundry in Devonshire to equalize the blast of the bellows, observed the intensity of Sound to be considerably augmented in the air thus compressed by their action. The same effect has been experienced in diving-bells. More recently M. Biot has repeated the experiment of the exhausted receiver, with a much more perfect vacuum than could be procured in Hanksbee's time; and found the Sound to be quite imperceptible, even when the ear was held close to the receiver, and all attention paid. (*Mém.* d'Arcueil, vol. ii. p. 97.)

Diminution of Sound in rarefied air.

Its increase in condensed air.

3. On high mountains. The diminution of the intensity of Sound in a rarefied atmosphere is a familiar phenomenon to those who are accustomed to ascend very high mountains. The deep silence of those elevated regions has a physical cause, independent of their habitual solitude. Saussure relates, that a pistol fired on the summit of Mont Blanc, produced no greater report than a little Indian cracker (*petit petard de Chine*) would have done in a room. (*Voyage dans les Alpes*, vol. vii. p. 337, § 2020.) We have ourselves had occasion to notice the comparatively small extent to which the voice can be heard, at an altitude of upwards of 13,000 feet on Monte Rosa. Observations on this point in the elevated passes of the Himalaya Mountains would be interesting. They should be made by the explosions of a small detonating pistol, loaded with a constant charge, and the distances should be measured; for the voice loses much of its force from the diminution of muscular energy in rarefied air, and distances are extravagantly underrated by estimation in such situations. The height, however, to which an atmosphere, or medium capable of conveying Sound extends, far exceeds any attainable on mountains, by balloons, or even by the lightest clouds. The great meteor of 1783 produced a distinct rumbling Sound, although its height above the earth's surface was full 50 miles at the time of its explosion. (See Sir Charles Blagden's interesting Paper, *Philosophical Transactions*, 1784.) The Sound produced by the explosion of the meteor of 1719, at an elevation of at least 69 miles, was heard as "the report of a very great cannon, or broadside;" shook the doors and windows of houses, and threw a looking-glass out of its frame and broke it. (Halley, *Philosophical Transactions*, vol. xxx. p. 978.) These heights are deduced by calculation from observations too unequivocal, and agreeing too well with each other, to allow of doubt. Scarcely less violent was the Sound caused by the bursting of the meteor of July 17, 1771, near Paris; the height of which, at the moment of the explosion, is assigned by Le Roy at 20,598 toises, or about 25 miles. (*Mém. Acad. Par.* 1771, p. 668.) The report of a meteor, in 1756, threw down several chimneys at Aix in Provence, and was taken for an earthquake. These instances, and others which might be adduced, are sufficient to show that Sound can be excited in, and conveyed by, air of an almost inconceivable tenuity (for such it must be at the heights here spoken of) provided the exciting cause be sufficiently powerful and extensive, neither of which qualities can be regarded as deficient in the case of fire-balls, such as those of 1719 and 1783, the latter of which was half a mile in diameter, and moved at the rate of 20 miles in a second. It may, however, be contended, and not without some probability, that at these enormous heights Sound may owe its propagation to some other medium more rare and elastic than air, and extending beyond the limits of the atmosphere of air and vapour.

Extent of the Sounding atmosphere.

4. Sound is not *instantaneously* conveyed from the sounding body to the ear. It requires time for its propagation. This is a matter of the most ordinary observation. We hear the blows of a hammer at a distance, a very sensible interval of time after we see them struck. The report of a gun is always heard later than the flash is seen, and

Sounds not instantaneously conveyed.

the interval is longer the more distant the gun. We estimate the distance of a thunder-storm by the length of the interval between the lightning and the thunder-clap, which often arrives when we have ceased to expect it. The report of the meteor of 1783 was heard at Windsor castle, ten minutes after its disappearance. This is, probably, the longest interval yet observed.

5.
Velocity of Sound.
Influence of the wind on it.

A great multitude of experiments have been made to determine the precise velocity of Sound. The earlier results differ more than might have been expected, from the influence of several causes not immediately obvious, but chiefly from want of due attention to the influence of the wind. It is evident from the mechanical concussion attending loud noises, that Sound consists in a motion of the air itself communicated along it by virtue of its elasticity, as a tremor runs along a stretched rope. If, then, the whole body of the air were moving in a contrary direction, with the velocity of Sound, it would never make its way against the stream at all; and, on the other hand, when the wind blows from the sounding body direct towards the ear, it is equally clear that the velocity of the wind itself will be added to that of Sound in still air. If a stone be thrown into a still lake, the waves spread with equal rapidity in all directions, in circles whose centre is the stone. If into a running river, they still form circles, but their centre is carried down the stream; and, in point of fact, the wave arrives opposite to a point of the bank *above* the place where the stone fell, later than a point at the same distance below it in proportion to the rapidity of the stream. Hence all experiments on the velocity of Sound ought to be made, if possible, either in calm weather, or in a direction at right angles to that of the wind.

6.
Various determinations of the velocity of Sound.

The assumption of 1300 feet per second for the velocity of Sound by Roberts, (*Phil. Trans.* 1694,) and the inaccurate determinations of Mersenne, Bayle, and Walker, (*Phil. Trans.* 1698,) which give respectively 1474, 1200, and 1305 feet, (the latter by a mean of 12 experiments disagreeing no less than 370 feet *inter se*,) scarcely deserve more mention than the rude guesses of Roberval and Gassendi, which differ by an amount nearly equal to the whole quantity to be measured; the former fixing it at 560 feet, the latter at 1473. The first experiments which appear to have been made with any degree of care, were those instituted by the Florentine Academy *Del Cimento*. It was observed in these that at a distance equal to 5739 English feet, the Sound of a harquebuss arrived five seconds after the flash; and repeating the experiment at half the distance, they found exactly half the time to be required. This gives, for the velocity of Sound, 1148 feet per second.

Cassini the Elder, Picard, and Roëmer, from experiments made at a distance of 1280 toises, as related by Duhamel in the *Hist. de l'Acad. Par.* assign 1172; while Flamsteed and Halley, from a series of observations at the Royal Observatory, the origin of the Sound being three miles distant, concluded the velocity to be 1142 feet per second.

7.
Derham's experiments.
Circumstances influencing the propagation of Sound.

In a Paper communicated to the Royal Society in 1708, by Dr. Derham, the subject of the velocity of Sound is investigated more fully and distinctly than had before been done, and with some degree of attention to a variety of circumstances which appear likely to influence its propagation. These are chiefly

1. The direction and velocity of the wind.
2. The amount of barometric pressure.
3. The temperature of the air through which the sound is conveyed.
4. Its hygrometrical state of moisture and dryness.
5. The actual weather, whether fog, rain, snow, sunshine, &c.
6. The nature of the Sound itself, whether produced by a blow, a gunshot, the voice, a musical instrument; its pitch, quality, and intensity.
7. The original direction impressed on the Sound—by turning, for instance, the muzzle of a gun one way or the other.
8. The nature and position of the surface over which the Sound is conveyed; whether smooth or rough, horizontal or sloping; moist or dry, &c.

8.

To all these circumstances, except the wind, Derham attributes no effect; and, in fact, none of them, except the temperature of the air, have been ascertained to exercise any material influence on the velocity; though many, indeed all, have a very powerful one on its intensity, or the loudness of the Sound as it reaches the ear from a given distance. The quantity of aqueous vapour indeed ought (as we shall see) to affect the velocity, but in a degree only appreciable in the most delicate experiments. Derham concludes, from the whole of his observations, that Sound is propagated at the rate of 1142 feet per second, agreeing with the result of Flamsteed and Halley, and with that of the Florentine Academicians; and as the distances of the stations employed were considerable, in one case amounting to upwards of 12 miles, this determination appears deserving of some reliance. The temperature, unfortunately, was not registered; so that the experiment loses much of its value from the impossibility of applying with certainty the requisite correction.

9.
Experiments of the French Academicians, 1738.
Mode of observing by reciprocal signals.

In 1737-1738, the Academy of Paris directed a reinvestigation of the subject, and Messrs. Cassini de Thury, Maraldi, and La Caille, who were at that time engaged in the triangulation of France, were charged with the conduct of the experiments; an account of which, by Cassini, is to be found in the volumes of the *Histoire de l'Acad.* for the latter year and for 1739. Their observations were carefully made, and the distance of the stations was considerable, (from 2931 to 16,079 toises.) In these experiments we find the first example of observations so disposed as to eliminate in some measure the disturbing effect of the wind. To apprehend how this may be done, let us suppose a current of wind to blow *uniformly* with any velocity from one station A to another B at any distance, and at these two stations let shots be fired. The Sound of the shot fired at A will then be accelerated, and that of the signal at B will be retarded, in traversing the interval, by equal quantities; and consequently (since the velocity of Sound is very much greater than that of the most violent wind) the time in which the Sound runs over the line A B will be diminished, and that in which it traverses B A increased, by equal quantities; so that the mean will be unaffected by the wind's velocity. In fact, supposing V to be the velocity of Sound, v that of the wind, and S the space described, the velocities of the Sound in the two opposite directions will be V + v and V − v; and the times of description of the space A B will be $\frac{S}{V+v}$ and $\frac{S}{V-v}$, whose mean is equal to $\frac{SV}{V^2-v^2}$, or to $\frac{S}{V}\left\{1+\left(\frac{v}{V}\right)^2+\left(\frac{v}{V}\right)^4+\&c.\right\}$, which when v is small with respect to V, reduces itself simply to $\frac{S}{V}$. The most violent hurricane moves at a rate less than one-tenth that of Sound; so that in the worst case the neglect of the terms depending on the velocity of the wind will entail an error less than $\frac{1}{99}$ of the whole result, or about 11 feet; and under ordinary circumstances such as are likely to be selected for experiment, their influence is quite inappreciable.

10. Influence of sudden gusts of wind.

It is evident, however, that any want of uniformity in the rate of the wind will destroy, so far as it goes, the precision of the result so obtained; and that, in consequence, if the corresponding signals are not *strictly simultaneous* so as to make the Sound traverse the same identical portion of the aerial current, a great part of the advantage of this mode of experimenting is lost. M. Arago has indeed remarked, that even in that case, if the wind be very irregular, and in sudden gusts, it will still affect the result; to conceive which, we will suppose a gust of wind to arise suddenly at the station A at the moment of firing the signals both at A and B. The Sound which proceeds in the direction A B, as it runs quicker than the wind, will leave it behind, and be propagated at every point of A B in still air, before the agitation of the wind has had time to reach it. On the other hand, the Sound from B will meet the wind; and, during the latter part of its course, at least, will be propagated in a moving atmosphere. Still, it will be observed, that it can be *only* the latter part of its course which can be thus affected, less, at all events, than one-tenth of the whole space; and the effect during that tenth being to retard the Sound by one-tenth at most of *that interval*, will produce a total effect, not exceeding a hundredth of the whole time of traversing A B; and, consequently, will affect the mean of the two deduced velocities by a quantity not exceeding a two-hundredth part of its value, or about five feet per second. We have already seen that the neglect of the square and higher powers of the velocity of the wind may in the same extreme case produce double this amount of error. This, however, is the error produced by a sudden gust equal to the most violent tornado. In ordinary winds, then, it must be quite inappreciable; and the method of simultaneous observations at opposite stations, provided they be *strictly* such, may be regarded as completely eliminating the wind's influence.

11. Cassini's result.

In the experiments of Cassini and his colleagues, however, none of these niceties were attended to; a long interval elapsed between the corresponding observations when obtained; and, indeed, the greater part of their series was made without any regard to correspondence at all. They conclude the velocity of Sound to be 173 toises, or 1106 British feet per second, at the temperature between 4° and 6° Reaum. at which the experiments were made. The extreme difference of velocities due to a favourable and a contrary wind they found to be about one-eleventh of the whole, giving $\frac{1}{22}$ for the ratio of the velocity of the wind to that of Sound as their maximum, or 50 feet per second. When the correction for the temperature of the air is applied, it will be seen presently that their result justifies the reliance placed on it by its authors; being, in fact, within about a yard of the truth.

12. Other determinations.

Nearly about the same time Bianconi in Italy, and La Condamine at Quito and at Cayenne, instituted a series of experiments for the same purpose, of which accounts will be found in the *Comment. Bonon.* ii. p. 365; in La Condamine's *Introduction Historique, &c.* 1751, p. 98; and in the *Mém. Acad. Par.* 1745, p. 448. But the theory of Sound being at that time but imperfectly understood, and the necessary corrections in consequence being not sufficiently, or not at all attended to, the subject has been regarded as still open to further discussion; and accordingly a great number of researches by later experimenters have been instituted, of which the principal are those by Müller in 1791, (*Götting. Gelehrte. Anzeigen*, 1791, No. 159;) by Espinosa and Bauza, in Chili, in 1794, (*Ann. de Chim.* vii. 93;) by Benzenberg in 1809, (Gilbert's, *Annalen*, new series, v. 383;) by Arago, Bouvard, Matthieu, Prony and Humboldt, and Gay Lussac, in 1822, (*Connaiss. des Temps*, 1825, p. 361;) by Moll, Vanbeek, and Kuytenbrouwer in Holland, in 1822, (*Phil. Trans.* 1824, p. 424;) by Mr. Goldingham, in 1820, at Madras, (*Phil. Trans.* 1823, p. 96;) by Dr. Gregory, at Woolwich, in 1823, (*Trans. of Cambridge Phil. Soc.* 1824;) and by General Myrbach and Professor Stampfer, at Saltzburg, (Jahrburh *des Polytekn. Instituts zu Wien*, vol. vii.)

13. Experiments of Moll, Vanbeek, &c. and of Arago, Matthieu, &c.

Of these by far the most considerable and circumstantial, as well as in all probability, from the instrumental means employed and precautions used, the most exact, are those of the Dutch and the Parisian Philosophers. Every attention was paid in them (at least in the case of the Dutch experimenters) to obtain signals *strictly* reciprocal, by guns fired at the same instant of time at the two ends of the line of observation; all those corrections depending on Meteorological circumstances which theory points out, and which it will be the object of subsequent parts of this Essay to explain, being carefully applied; and the distances of the stations being at once considerable, and determined with sufficient exactness by Trigonometrical operations.

14. Methods of measuring very small portions of time.

One very material difficulty in the way of former observers (Benzenberg excepted) lay in the want of adequate means of measuring with precision intervals of time to a minute fraction of a second. This difficulty was obviated in the experiments of the French Commissioners, by the use of the stop-watch of Breguet, and the *chronograph* of Rieussec, a species of watch, one of whose hands performs a revolution per second, and can be made to touch with its extremity the dial-plate, at any instant, and leave there a dot, without interrupting its motion of rotation, by the sudden pressure of a small lever; to effect which it carries with it a drop of printer's ink in a peculiar and ingenious species of dotting pen. In the Dutch experiments, a clock with a conical pendulum was used, capable of determining intervals to the hundredth of a second, by suddenly suspending the motion of the index, without stopping the clock. By the use of these instruments it was found practicable to ascertain the interval between the sight of the flash, and the arrival of the report, of a gun, with such precision as to destroy all material error in the result which might arise from this cause; an improvement of great importance, when we consider that an error of a single tenth of a second in the measure of time is equivalent to 110 feet in that of distance.

15. Their results. The close agreement of the results of these experiments is a convincing proof of their accuracy. The French Philosophers state 331·05 met. = 1086·1 feet, as the velocity of propagation of Sound in air of the temperature of freezing water, while the Dutch experimenters make it 332·05 met. = 1089·42 feet in perfectly dry air of the same temperature. The latter seems to deserve the preference. if only from the circumstance of the signals from which it is deduced having been strictly simultaneous, the guns at the two extremities of the line (nine miles in length) having been fired at the same second of time, while in the former series this exact coincidence was not obtained.

16. Synoptic view of results. We subjoin a list of the results arrived at in the various determinations above enumerated, with their dates, the distances of the stations employed, &c. to bring the whole subject under one view.

Table I.—*Velocity of Sound as determined by various Experiments.*

Observers' Names.	Date of Determination. A. D.	Distance of Stations in Feet.	Velocity in English Feet per second.	Remarks.
Mersenne	....	....	1474	
Florentine Academicians	1660	5906	1148	Moll and Vanbeek state this result at 361 metres = 1184 feet. Our authorities are Derham and Walker.
Roberval	....	....	560	
Gassendi	....	....	1473	
Boyle	....	....	1200	*Essay of Languid Motion.*
Roberts	1694	....	1300	No experiments stated.
Walker	1698	variable 600 to 2370	1305	By return of echos in given times and measuring distance.
Cassini, Picard, Roëmer	....	8186	1172	Duhamel.
Cassini, Huygens	....	9239	1151	Moll on authority of Duhamel.
Flamsteed, Halley	....	15840	1142	As stated by Derham.
Derham	1704	5280 to 63360	1142	
Cassini de Thury, Maraldi, Lacaille	1738	18744 to 102824	1106	Near Paris at Montlhery, Dammartin, &c. Therm. +5° Reaum..consider their result as within a fathom of the truth.
	....	....	1093	Do. reduced to freezing temperature.
Cassini, Lacaille	1739	144124	1110	Between Sette and Aiguesmortes, *Mém. Acad. Par.* 1739, p. 127, temperature not stated, probably about + 6° R.
Bianconi	1740	78740	1043	
La Condamine	1740	67400	1112	At Quito.
La Condamine	1744	129360	1175	At Cayenne.
Millington	....	....	1130	Cited by Goldingham, (*Phil. Trans.* 1823.)
T. F. Mayer	1778	3412	1105	
G. E. Müller	1791	8530	1109	
Pictet	....	....	1130	Cited by Dr. Gregory, (*Trans. Phil. Soc. Cambridge*, ii. 120.)
Espinosa and Bauza	1794	53626 to 14071	1222·23	At Chili, at a temperature = 74° 7′ Fahr. mean of four determinations, and mean temperature, the mean taken giving a weight to each proportional to the distance.
Benzenberg, (Dusseldorff)	1809	29764	1093	At freezing temperature.
Arago, Matthieu, Prony, Bouvard, Humboldt	1822	61064	1086·1	At freezing temperature, (between Villejuif and Montlhery.)
Moll, Vanbeek, Kuytenbrouwer	1823	57839	1089·42	In dry air, at freezing temperature.
Gregory	1823	Various 2700 to 13460	1088·05	Mean of eight results given by Dr. Gregory, each separately reduced to the freezing temperature.
Myrbach	1822	32615	1092·1	Mean of 88 observations reduced to the freezing temperature difference of level of stations = 4474.
Goldingham, (Madras)	1821	29547 13932 mean	1089·9 1079·9 1086·7	Hygrom. 20·31 Hygrom. 11·85 Mean .. 17·4 Reduced to the freezing temperature. The mean taken by attributing to each determination a weight proportional to the distance of the stations. The nature of the hygrometer not stated.

17. The agreement between such of the above results as are reduced to the standard or freezing temperature, *i. e.* of the last six, and the first determination of Cassini at Paris, is very close; their extreme discrepancy being less than seven feet, or a 160th of the whole amount, and their mean (1089·7) agreeing almost precisely with the result of Moll, Vanbeek, &c.; we may, therefore, adopt 1090 feet without hesitation (as a whole number) as no doubt

within a yard of the truth, and probably within a foot. The reduction to the zero of temperature has been made (when not performed by the authors themselves) on the supposition that every additional degree of atmospheric temperature, on Fahrenheit's scale, adds 1·14 foot to the velocity, a correction of which the grounds will be hereafter explained. (See Art. 68.)

Velocity finally adopted = 1090 feet per second.

18.
Approximations in round numbers.

It may, therefore, be stated in round numbers, that Sound, in dry air and at the freezing temperature, travels at the rate of 1090 feet, or 363 yards per second, and that at 62° Fahrenheit (which is the standard temperature of the British metrical system) it runs over 9000 feet in eight seconds, 12¾ British standard miles in a minute, or 765 miles in an hour, which is about three-fourths of the diurnal velocity of the Earth's equator.

19.
Comparison with the Earth's diurnal motion.

Hence, in latitude 42½°, (42° 29′ 40″,) if a gun be fired at the moment a star passes the meridian of any station, the Sound will reach any other station exactly west of it at the precise instant of the same star's arriving on *its* meridian.

20.
Remarks on some of the above results.

In the experiments of Dr. Gregory, the velocity of the wind was measured by an anemometer, and allowed for. The close agreement of their results with those of the Dutch and French observers, when the smallness of the distances is taken into consideration, is a strong proof of the care and accuracy with which they were made. The observations of Mr. Goldingham, or at least his mode of stating and reducing them, has been strongly, but we think undeservedly, censured in Poggendorff's *Annalen der Physik*, 81. Band. s. 490. He takes a mean of all the velocities observed daily, in calm weather, during a very long time, by the firing of a morning and evening gun at two stations visible from Madras, and a mean of all the temperatures, pressures, and hygrometer-readings. All that we have done is to apply the correction for this mean temperature to his mean velocities, as if they had been given by a single observation, a course, no doubt, perfectly legitimate, and saving a world of calculation. It is to be lamented that the nature of his hygrometer is not stated, as its indications at present are perfectly useless. The experiments of Espinosa and Bauza differ so enormously in their result from the rest, even when reduced to the freezing temperature, that most probably some fundamental mistake, either in their measurement of the distances, or in the calculations founded on them, must have been committed. Our authority is the *Annales de Chimie*, vol. vii. (N. S.) p. 93.

21.
Effect of fogs, &c. to obstruct Sound.
Sound, well conveyed over water and smooth ice.

Derham found that fogs and falling rain, but especially snow, tend powerfully to obstruct the free propagation of Sound, and that the same effect was likewise produced by a coating of fresh fallen snow on the ground, though when glazed and hardened at the surface by freezing it had no such influence. Over water, or a surface of ice, Sound is propagated with remarkable clearness and strength. Dr. Hutton relates, that on a quiet part of the Thames, near Chelsea, he could hear a person read distinctly at 140 feet distance, while on the land the same could only be heard at 76. Lieutenant Foster, in the third Polar Expedition of Captain Parry, found that he could hold a conversation with a man across the harbour of Port Bowen, a distance of 6696 feet, or about a mile and a quarter. This, however remarkable, falls far short of what is related by Dr. Young on the authority of Derham, *viz.* that at Gibraltar the human voice has been heard ten miles, (perhaps across the Strait.) We have not been able to find the original passage either in his *Physico-Theology*, or in his dissertation *De Soni Motu*, in both which very remarkable instances are adduced, of which the following will suffice as specimens.

22.
Distances at which Sounds have been heard.

Guns fired at Carlscroon were heard across the southern extremity of Sweden as far as Denmark; 80 miles, as Derham states from memory, but according to the map at least 120.

Dr. Hearn, a Swedish physician, relates that he heard guns fired at Stockholm, on the occasion of the death of one of the Royal family in 1685, at the distance of 30 Swedish, or 180 British miles.

The cannonade of a sea-fight between the English and Dutch, in 1672, was heard across England as far as Shrewsbury, and even in Wales, a distance of upwards of 200 miles from the scene of action.

23.
All sounds travel with equal velocity.

That Sounds of all pitches, and of every quality, travel with equal speed, we have a convincing proof in the performance of a rapid piece of music by a band at a distance. Were there the slightest difference of velocity in the Sounds of different notes, they could not reach our ears in the same precise order, and at the exact intervals of time in which they are played, nor would the component notes of a harmony, in which several Sounds of different pitch concur, arrive at once. M. Biot caused several airs to be played on a flute at the end of a pipe 951 metres, or 3120 feet, long, which were distinctly heard by him at the other end, without the slightest derangement in the order or intervals of sequence of the high and low notes. (*Mém. d'*Arcueil, ii. 422.) A better form of the experiment would have been to strike two bells of very different pitch one against the other, having removed their clappers. Both their sounds would (no doubt) arrive together.

24.
Effect of pipes in conveying Sound.

A very material difference, however, is observed in the *intensity* with which Sounds are propagated, or the distances to which they may be heard with equal distinctness according to a great variety of circumstances. Thus, if a Sound be prevented from spreading and losing itself in the air, whether by a pipe, by the vicinity of an extensive flat surface, as a wall, or otherwise, it may be conveyed to very great distances with little diminution of force. This we observe familiarly in speaking pipes conducted from one apartment to another of a building. In the experiments already cited of M. Biot, a person being stationed at one end of the enormous tube above mentioned, (which was a combination of cast iron conduit pipes laid down for the supply of Paris with water, forming a continuous canal of equal internal diameter throughout, and having two flexures about the middle of its length) the lowest whisper at one end was distinctly heard at the other, so that, in fact, the only way not to be heard was not to speak at all. Nay, so faithful was the transmission of every agitation of the air, whether sonorous, or otherwise, along the pipe, that a pistol fired at one end actually blew out a candle at the other, and drove out light substances placed there with considerable violence.

25.
Sound in Carisbrook Well.

At Carisbrook Castle, near Newport, in the Isle of Wight, is a well, 210 feet in depth, and 12 in diameter, into which if a pin be dropped, it will be distinctly heard to strike the water. The interior is lined with very smooth masonry.

26.

It is evident, without entering into any nice theoretical considerations, that a mechanical impulse of whatever nature impressed on any portion of the air or other medium, whether fluid or solid, and thence communicated

Conveyance of Sound along a wall.

to the surrounding parts, if allowed to spread in all directions as from a centre, must reach every more distant point with an energy continually less and less, because the same quantity of motion is communicated in succession to a larger and larger sphere of inert matter, but if only allowed to spread in certain directions, its diminution will be less rapid in proportion as the quantity of matter successively put in motion increases less rapidly. Hence a Sound might be expected to be conveyed with less diminution along a wall than in the open air, the trough or angle between the wall and the ground, in fact, forming two sides of a square pipe, and the divergence of the Sound in two directions being thereby in great measure prevented. Dr. Hutton relates that part of the wall of a garden, formerly in the possession of W. Pitt, Esq. of Kingston, in Dorsetshire, conveys a whisper in this way nearly 200 feet. (*Mathematical Dictionary*, Article *Sound*.) It is probably to some such principle that we must refer a fact mentioned by the last-named author, which at first sight appears surprising enough. He relates that when a canal of water was laid under the pit floor of the Theatre *Del Argentino*, at Rome, a surprising difference was observed. The voice has since been heard very distinctly when it was before scarcely distinguishable. It is a general remark that Sounds are well heard in buildings which stand on arches over water. The cause of this, however, seems to be the echo produced between the water and the arch which unites with, and reinforces, the original Sound. The Work just referred to contains many curious instances of the kind.

27. Echos. Their nature.

When Sound in the course of its propagation meets with an obstacle of sufficient extent and regularity it is reflected, producing the phenomenon we call an *Echo*. A wall, the side of a house, or the surface of a rock, the ceiling, floor, and walls of an apartment, the vaulted roof of a church, all, under proper circumstances, give rise to Echos more or less audible. The reflected Sound meeting another such obstacle is again reflected, and thus the Echo may be repeated many times in succession, becoming, however, fainter at each repetition till it dies away altogether. We shall here set down a few localities in which Echos, remarkable either for distinctness, or frequency of repetition, may be heard.

28. Instances of remarkable Echos.

An Echo in Woodstock Park, (Oxfordshire,) repeats 17 syllables by day, and 20 by night, (Plot, *Nat. Hist. Oxford*. ch. i. p. 7.) One on the banks of the Lago del Lupo, above the fall of Terni, repeats 15.

29. In the Abbey Church of St. Alban's is a curious Echo. The tick of a watch may be heard from one end of the church to the other. In Gloucester Cathedral, a gallery of an octagonal form conveys a whisper 75 feet across the nave.

30 An Echo on the north side of Shipley Church, in Sussex, repeats 21 syllables. (Cavallo, citing Plot and Harris.)

31. Echo in the Cathedral at Girgenti.

In the Cathedral of Girgenti, in Sicily, the slightest whisper is borne with perfect distinctness from the great western door to the cornice behind the high altar, a distance of 250 feet. By a most unlucky coincidence the precise focus of divergence at the former station was chosen for the place of the confessional. Secrets never intended for the public ear thus became known, to the dismay of the confessors, and the scandal of the people, by the resort of the curious to the opposite point, (which seems to have been discovered accidentally,) till at length, one listener having had his curiosity somewhat over-gratified by hearing his wife's avowal of her own infidelity, this tell-tale peculiarity became generally known, and the confessional was removed. (*Travels through Sicily and the Lipari Islands, in the Month of December*, 1824. By a Naval Officer. 1 vol. 8vo. London, 1827.)

32. In the Whispering Gallery of St. Paul's, London, the faintest Sound is faithfully conveyed from one side to the other of the dome, but is not heard at any intermediate point.

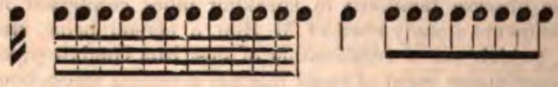
33. In the Manfroni Palace at Venice is a square room about 25 feet high, with a concave roof, in which a person standing in the centre, and stamping gently with his foot on the floor, hears the Sound repeated a great many times, but as his position deviates from the centre the reflected Sounds grow fainter, and at a short distance wholly cease. The same phenomenon occurs in the large room of the Library of the Museum at Naples.

34. Echo in the Simonetta Palace.

Southwell (*Phil. Trans.* 1746, 223.) describes an Echo in an old Palace near Milan, which repeated the report of a pistol 56, or even 60 times. His description is singularly confused, but the palace is no doubt that of Simonetta, mentioned by Addison in his *Travels*. This was a building with two wings, forming three sides of a square. The pistol was discharged from a window in one wing, the Sound was returned from a dead wall in the other wing, and heard from a window in the back front. (Hutton, Art. *Echo*. Misson, *Voy. d'Ital.* ii. 196.) The Palace still exists, but ear-witnesses have described the phenomenon to us somewhat differently. The Echos are heard at the window whence the pistol is fired.

35. Echo under the Menai Bridge.

Beneath the Suspension Bridge across the Menai Strait, in Wales, close to one of the main piers, is a remarkably fine Echo. The Sound of a blow on the pier with a hammer, is returned in succession from each of the cross-beams which support the roadway, and from the opposite pier at a distance of 576 feet, and, in addition to this, the Sound is many times repeated between the water and the roadway. The effect is a series of Sounds which may be thus written



&c.; the first return is sharp and strong, from the roadway over head, the rattling which succeeds dies away rapidly, but the single repercussion from the opposite pier is very strong, and is succeeded by a faint palpitation, repeating the Sound at the rate of 28 times in five seconds, and which therefore corresponds to a distance of 184 feet, or very nearly the double interval from the roadway to the water. Thus it appears, that in the repercussion between the water and roadway, that from the latter only affects the ear, the line drawn from the auditor to the water being too oblique for the Sound to diverge sufficiently in that direction. Another peculiarity deserves especial notice; *viz.* that the Echo from the opposite pier is best heard when the auditor stands precisely opposite to the middle of the breadth of the pier and strikes just on that point. As he deviates to one or the other side the return is proportionably fainter, and is scarcely heard by him when his station is a little beyond the extreme edge of

Equality of the angles of incidence and reflexion.

the pier, though another person stationed (on the same side of the water) at an equal distance from the central point, so as to have the pier between them, hears it well. Thus, in the reflexion of Sound, there is an evident approach to the law of equality between the angles of incidence and reflexion which obtains in that of Light; and a tendency in the reflected Sound to confine itself to the direction which a ray of Light regularly reflected at the echoing surface would follow, and not to spread into the surrounding air equally in all directions. This experiment (which we had an opportunity of making, with the assistance of Mr. Babbage, in 1827) might be carried much farther under more favourable circumstances; and, we doubt not, would lead to remarkable confirmations of the law of interference, and the general analogy between Sound and Light, to which all Optical and Acoustical phenomena point, and of which we shall have occasion to say more hereafter. (See also our Essay on LIGHT.) The span of the bridge between the piers is 576 feet, and the breadth of each pier about 30 feet.

36. Situations favourable to Echos.

The most favourable position for the production of a distinct Echo from plane surfaces is, when the auditor is placed between two such, exactly half way. In this situation the Sounds reverberated from both will reach him at the same instant, and reinforce each other. If nearer to one surface than the other, the one will reach him sooner than the other, and the Echo will be double and confused. If the Echoing surface be concave towards him, the sounds reflected from its several points will, after reflexion, converge towards him, exactly as reflected rays of Light do; and he will receive a Sound more intense than if the surface were plane, and the more so the nearer it approaches to a sphere concentric with himself: the contrary if convex. If the Echo of a Sound excited at one station be required to be heard most intensely at another, the two stations ought to be *conjugate foci* of the reflecting surface, *i. e.* such that if the reflecting surface were polished, rays of Light diverging from one would be made after reflection to converge to the other. Hence if a vault be in the form of a hollow ellipsoid of revolution, and a speaker be placed in one focus, his words will be heard by an auditor in the other as if his ear were close to the other's lips. The same will hold good if the vault be composed of two segments of paraboloids, having a common axis, and their concavities turned towards each other; only in this case, Sounds excited in the focus of one segment will be collected in the focus of the other, after two reflexions.

37. Effect of Echos in Churches and public buildings.

An attention to the doctrine of Echos is of some, though we think a rather overrated, importance to the architect in the construction of buildings intended for public speaking, or music, especially if they be large. In small buildings, the velocity of Sound is such that the dimensions of the building are traversed by the reflected Sound in a time too small to admit of the Echo being distinguished from the principal Sound. In great ones, on the other hand, as in Churches, Theatres, and Concert rooms, the Echo is heard after the principal Sound has ceased; and if the building be so constructed as to return several Echos in very different times, the effect will be unpleasant. It is owing to this that in Cathedrals the service is usually read in a sustained uniform tone, rather that of singing than speaking, the voice being thus blended in unison with its Echo. A good reader will time his syllables, if possible, so as to make one fall in with the Echo of the last, which will thus be merged in the louder Sound, and produce less confusion in his delivery. For music, in apartments of moderate size, all objects which can obstruct the free reflexion of Sound from the walls, floor, and ceiling are injurious. The Echo is not sensibly prolonged after the original Sound, and therefore only tends to reinforce it, and is of course highly advantageous. In large ones, an Echo can only be advantageous in the performance of slow pieces, (as Church music.) The prolongation of a chord, after the harmony is changed, can be productive of nothing but dissonance. When ten notes succeed one another in a second, as is often the case in modern music, the longitudinal Echo of a room 55 feet long, will precisely throw the second reverberation of each note on the principal Sound of the following one wherever the auditor be placed; which, in most cases, will produce (in so far as it is heard) only discord. Much mistake seems to be prevalent on this subject. Thus it is said that the form of an orchestra should be parabolic, &c. that the rays of Sound should be reflected out in parallel lines to the audience. But even if they were so, the reflected Sound cannot possibly reach them in the same *time* with the direct; and in Acoustics it is of little moment in what direction sounds reach the ear, which is not, like the eye, capable of appreciating direction with any precision, or collecting the rays or waves of Sound to a focus within the ear. It is not possible to place a whole band in the focus of a parabolic or elliptic orchestra, or a whole audience in that of a corresponding opposite segment. We may add, too, that an apartment would be worse lighted, were its internal surface a polished semi-ellipsoid, with a candle in the focus, than if it were of the usual shape, and its walls and ceiling a dead white. The object to be aimed at in a Concert-room is, not to deafen a favoured few, but to fill the whole chamber equally with Sound, and yet allow the Echo as little power to disturb the principal Sound, by a lingering after-twang, as possible. But, whether for music or for oratory, open windows, deep recesses, hangings, or carpeting, and a numerous audience in woollen clothing, are all unfavourable to good hearing. They are to Sound, what black spaces in an apartment would be to light; they return back none, or next to none, of what falls on them. Their fault is not so much that they reflect it irregularly, as that they do not reflect it at all.

38. Reverberation of Sound from the clouds.

The rolling of thunder has been attributed to Echos among the clouds; and if it is considered that a cloud is a collection of particles of water, however minute, yet in a liquid state, and therefore each individually capable of reflecting Sound, there is no reason why very loud Sounds should not be reverberated confusedly (like bright lights) from a cloud. And that such is the case, has been ascertained by direct observation on the Sound of cannon. Messrs. Arago, Matthieu, and Prony, in their experiments on the velocity of Sound, observed, that under a perfectly clear sky, the explosions of their guns were always heard single and sharp, whereas when the sky was overcast, or even when a cloud came in sight over any considerable part of the horizon, they were frequently accompanied with a long continued roll like thunder, and occasionally a double Sound would arrive from a single shot.

39. Explanation of thunder

But there is, doubtless, also another cause for the rolling of thunder, as well as for all its sudden and capricious bursts and variations of intensity, of which our knowledge of the velocity of Sound furnishes a perfect explanation. To understand this, we must premise that, *cæteris paribus*, the estimated intensity of a Sound will be proportional to the quantity of it (if we may so express ourselves) which reaches the ear in a given time. Two blows equally loud, at *precisely the same distance from the ear*, will Sound as one of double the intensity; a hundred, struck in an instant of time, will sound as one blow a hundred times more intense than if they followed in such slow succession that the ear could appreciate them singly. Now let us conceive two equal flashes of lightning, each four miles long, both beginning at points equidistant from the auditor, but the one running out in a straight line directly away from him; the other describing an arc of a circle having him in its centre. Since the velocity of Electricity is incomparably greater than that of Sound, the thunder may be regarded as *originating* at one and the same instant in every point of the course of either flash. But it will reach the ear under very different circumstances in the two cases. In that of the circular flash, the Sound from every point will arrive at the same instant, and affect the ear as a single explosion of stunning loudness. In that of the rectilinear flash, on the other hand, the Sound from the nearest point will arrive sooner than from those at a greater distance; and those from different points will arrive in succession, occupying altogether a time equal to that required by Sound to run over four miles, or about 20 seconds. Thus the same *amount* of Sound is in the latter case distributed uniformly over 20 seconds of time, which in the former arrives at a single burst; of course, it will have the effect of a long roar, diminishing in intensity as it comes from a greater and greater distance. If the flash be inclined in direction, the Sound will reach the ear *more compactly*, (*i. e.* in shorter time from its commencement,) and be proportionally more intense. If (as is almost always the case) the flash be zigzag, and composed of broken rectilinear and curvilinear portions, some concave, some convex to the ear; and if, especially, the principal trunk separates into many branches, each breaking its own way through the air, and each becoming a separate source of thunder, all the varieties of that awful Sound are easily accounted for.

40. Phenomenon observed in the eruptions of volcanos.

We will only mention one other phenomenon which is accountable for on the same principle. In the eruption of a volcano it is often remarked, that every ejection of stones, &c. is accompanied with an explosion like artillery when heard at a distance; but when near, the Sound resembles rather that of a loud and deep sigh, unaccompanied with any sudden burst. In both cases the cause of Sound is the same, the upward rush and displacement of the air by the stone; but where the auditor is near the bottom of the column of Sound, it reaches his ear more in detail than when at a distance, and therefore nearly equidistant from all its parts. In fact, let $t =$ the time taken by the stone to rise to a height x, and let a be the distance of the observer from the bottom of the column, and v the velocity of Sound, then will $t + \frac{\sqrt{a^2 + x^2}}{v} =$ time elapsed from the moment of ejection to that of the Sound of the column at the height x reaching the ear. Hence the whole Sound of the portion x of the column will arrive in an interval of time represented by $t + \frac{\sqrt{a^2 + x^2} - a}{v}$. Now, as a increases, x, and therefore t remaining constant, this function diminishes rapidly, and ultimately approaches t as its limit. Thus the Sound arrives continually more and more condensed. Should any discharge be made obliquely towards the observer's station, a still greater concentration of the noise will happen, as may be easily seen by considering that if shot directly towards him, with the velocity of Sound, the report would reach him from every part of the line strictly at the same moment. Now, as these ejections have been known to rise to a height of 10,000 feet, in spite of the resistance of the air, their initial velocity must be, at least, equal to that of Sound. At great distances it is probable that only the Sounds produced by such oblique ejections have intensity or (as we may express it) body enough to affect the sense.

§ II. *Mathematical Theory of the Propagation of Sound in Air, and other Elastic Fluid Media.*

41. General notion of the communication of motions in elastic media.

Propagation of tremors along a stretched cord.

Fig. 1.

Fig. 2.

A general notion of the mode in which an impulse communicated to one portion of the air, or other elastic fluid, is diffused through the surrounding portions, and successively propagated to portions at a greater and greater distance from the original source of the motion, may be obtained by considering the way in which a tremor runs along a stretched cord, or in which waves excited in the surface of still water dilate themselves circularly, and propagate a motion impressed on one point of the surface, in all directions to a distance. In the former case, conceive a blow given to a point in the middle of the cord, transversely to its length. The point to which the blow is given will be thrown out of the straight line, and a flexure, or angle, will be formed in that part. Owing, however, to the inertia of the cord, the displacement of the particles in the first instant will be confined to the immediate neighbourhood of the point of impulse; so that the cord will not at once assume the state represented in fig. 1, consisting of two straight portions A B, B C, forming a very obtuse angle A B C; but rather that in fig. 2, in which the greater part on either side A D, D C, retain their original position; and a small part D B E, proportioned to the violence and suddenness of the blow, is, as it were, bulged out into an angular form D B E. The particle at B then is solicited on both sides by the tension of the cord in directions B D, B E; but these tensions, which in the quiescent state of the string exactly counteracted each other, now only do so in respect of those parts of each which, when resolved, act in directions parallel to D A, E C respectively. The other resolved portions, perpendicular to these, conspire and urge the point B towards its point of departure *b*. As there is no force to counteract this (the impulse being supposed momentary) B will obey their solicitation, and approach *b* with an accelerated velocity. But, action and reaction being equal and contrary, the same force by which the molecule E drags B *down*, will be exerted on E to drag it *up*, or out of the line; so that by the time B has performed half its course towards *b*, E will have been raised above the line, and will have acquired a velocity capable of carrying it still further in that direction. At this instant the cord will have assumed the figure A D′ D B E E′ C. At the next moment the forces are reversed, B then tends to drag both D and E down to the line; but its own acquired momentum is expended in the effort, and by the time it has reached its original place in the line, its inertia is destroyed, and it rests there without a tendency to go beyond it on the other side. Meanwhile, however, D and E have attained their greatest elevation; and thus the protuberance D B E is resolved into two D′ D B and B E E′ (of less height, however) on either side. In like manner the particles D and E, in returning to their places, drag up the next adjoining D′ and E′, and then the next, and so on; and thus the summits of the protuberances advance along the line, and correspond in succession to all its points; and the visible effect is an undulation, or wave, which runs along the cord with a velocity greater the greater is the force with which the cord is strained, as it manifestly ought to be, since the rapidity with which each molecule returns from its displaced situation is greater as the force urging it is so; and this force is nothing more than the resolved part of the tension.

42. Propagation of waves in still water.

In like manner, when a wave is excited in the surface of water, as when by throwing in a stone one portion is violently driven down, and the surrounding part heaped up above its natural level; this subsides and fills up the vacuity; but as its pressure takes place alike on both sides of the ridge, the fluid on the outside of the ridge is also pressed on, from below upwards, by the reaction of the fluid stratum which sustains the ridge, and whose pressure is propagated equally in all directions. Thus the ridge, in subsiding, not only fills up the central vacancy, but forces up another ridge exterior to it; and this, in subsiding, another, and so on; and thus an advancing wave is formed; and the same action taking place on all sides of the centre, the wave can advance no otherwise than in the direction of radii on all sides diverging therefrom.

43.

It is by no means intended, in what is here said, to give an accurate account of what passes in either of these cases, (in fact, it is very far from being so, as the reader by a little attention will soon perceive,) but only to give a first conception of the propagation of motion by undulations or waves.

44. A wave not a progressive moving body but an advancing form.

In this general account of the above cases, one thing, however, cannot fail to strike the reader, that the *wave* which advances on the surface of water—the sinuosity which runs along the stretched cord—are neither of them things, but *forms*. They are not moving masses advancing in the direction in which they appear to run, but outlines, or figures, which at each instant of time include all the particles of the water or the cord which, it is true, *are* moving, but whose motion is in fact *transverse* to the direction in which the waves advance. But this is by no means an essential condition. We may generalize this idea of a *wave*, and conceive it as the form, space, or outline, whether linear or superficial, comprehending all the particles of an undulating body which are at once in motion, (supposing, for the present, that the motion of each consists of a simple displacement and return to quiescence, and not in a repetition of several such displacements and returns in succession.)

45. Example. Waves in a field of standing corn.

The waves in a field of standing corn, as a gust of wind passes over it, afford a familiar example of the relation between the motion of the wave, and that of the particles of the waving body comprised within its limits, and of the mutual independence which may in certain cases subsist between these two motions. The gust in its progress depresses each ear, in its own direction, which, so soon as the pressure is removed, not only returns, by its elasticity, to its original upright situation, but by the impetus it has thus acquired, surpasses it, and bends over as much, or nearly as much, on the other side; and so on alternately, oscillating backwards and forwards in equal times, but continually through less and less spaces, till it is reduced to rest by the resistance of the air. Such is the motion of each individual ear; and as the wind passes over all of them in succession, and bends each equally, all their motions are so far similar. But they differ in this, that they commence not at once, but successively. Suppose (to fix our ideas) the wind runs over 100 feet in a second, and that the ears stand one foot asunder, and each makes one complete vibration to and fro in a second. Suppose A (fig. 3) to be the furthest point which the wind at any given instant of time has reached, or the last ear which it has just bent, and let the action of the wind be regarded as lasting only for a single instant. Then will the next preceding ear B have already begun to rise from its bent position, the next C will have risen rather more, and the 25th ear G (since the distance A F is 25 feet, and consequently since $\frac{25}{100} = \frac{1}{4}$ of a second have elapsed since the wind was at G) will have gone through one-fourth of its complete vibration to and fro, and will have therefore just attained its upright position; so that the ears F, E immediately adjacent towards A will not yet have quite recovered their perpendicularity, but still lean somewhat forwards; while those on the other side H, I will have surpassed the perpendicular, and have begun to sway backwards; consequently at G the stalks will on both sides be convex towards G, and the ears in that place will be further asunder than in their state of rest, and will appear as it were *rarefied* when viewed by a spectator so distant as to take in a great extent at once. Still further in rear of the wind, as 50 feet, at L, the 50th ear will have swung backwards as far as possible, and will just have its motion destroyed. The preceding stalk, K, will still want somewhat of its extreme backward flexure; the subsequent one, M, will already have risen a little, and therefore the interval of the ears K, N will be just what it was in the state of rest. At L, then, the spectator will see the ears at their natural distances from each other. Again the 75th stalk, Q, in rear of the wind will have had time to rise again erect from its *backward* inclination, three-fourths of a second having elapsed since its first bending forward. The 74th, P, will not be quite erected; the 76th will have surpassed the erect state, and have again begun to lean forward. The stalks then on both sides of Q will curve *towards* Q, and their ears will therefore be closer together than in their natural state, and will appear *condensed* to the spectator above mentioned. Finally, the 99th, 100th, and 101st ears will be again in the same relative state as the 49th, 50th, and 51st; only leaning forwards instead of backwards, and therefore neither condensed nor rarefied. The field, then, will present to the spectator a series of alternate condensations and rarefactions of the corn ears, separated by intervals in their natural state of density; and this series will extend so far in rear of the wind, till the resistance of the air and want of perfect elasticity in the stalks shall

Fig. 3.

have reduced them to rest, and these alternations, by the difference of shading they offer, will become apparent to his sight as dark and bright zones.

46. Velocity of the wave distinguished from that of its component parts.

It matters not, for our present purpose, that the impulse is, in the case here taken, not propagated mechanically from ear to ear by mutual impulse, but that each moves independently of all the rest. All we want to illustrate is the distinction between the *wave* and the *moving matter*, and the independence of their motions. The waves here run along with the speed of the wind, whatever that may be; for it is always the point 25 feet in rear of the wind that is most rarefied, and that at 75 that is most condensed; and the interval between the first and 100th ear, comprehending ears in every state or *phase* of their vibrations, is what we term a wave. The *velocity* of the wave, then, is, in this case, that of the wind; and is totally distinct from, and independent of, that of each or any particular ear. The one is a constant, the other a variable quantity; the one a general resulting phenomenon, the other a particular, individual, mechanical process, going on according to its own laws.

47. And independent of their excursions from the state of rest.

Neither is it of the least consequence whether the excursions of the several stalks from their position of rest be great or little; whether the degree of bending, or force of the wind, be great or small, provided its velocity be constant. In the case of wind, indeed, the force depends on the velocity; but if we conceive the impulse given by a rigid rod made to sweep across the field, any greater or less degree of flexure might be given, with the same velocity, by a mere change of its level; but the velocity of the wave would still be that of the rod in every case.

48. Breadth of the waves.

But with respect to the *breadth* of the wave, or the magnitude of that interval which comprises particles in every *phase* or state of their motion, going and returning, it is otherwise. This is a result depending essentially on the motions of the particles themselves; for we see evidently in the above instance, that this breadth, which is 100 feet, is equal to the space run over by the wind in a time equal to that of one complete vibration, going and returning, of each individual ear. Now this time depends only on the elasticity of the stalk, and the weight of the ear it carries. In general then we may state, that "The breadth of a wave is equal to the space run over by it in a time equal to that in which any molecule of the waving body performs one complete vibration, going and returning, through all the phases of its motion." In the case here taken, the motion of the individual molecules is not, as in the former instances, transverse to that of the wave, but parallel to it. It is then hardly to be termed a *form*, or an *outline*. To such a wave, the term *pulse* is often applied. Whatever be the nature of the internal motions, however, the general name wave or undulation will equally apply, and will be used in future indiscriminately for all sorts of propagated impulses. It is not even necessary that the motions of the constituent particles should be rectilinear, or even lie in one plane. We may suppose the impelling cause to be a whirlwind. In this case each ear will have a rotatory or twirling motion, or the stalk a conical one, simply, or in addition to its flexure in a vertical plane; but the wave is independent of these particularities.

Various species of waves.

49. Sonorous waves propagated in air.

In the case just described, each particle is supposed to be set in motion by an external cause, and to be uninfluenced in its motions by the rest. It is, therefore, not a case of the *propagation* of motion at all. It is quite otherwise with Sound, or other similar cases, where every particle of a medium receives its whole motion from those which were moving before, and transmits it to others previously at rest. The problem to investigate the general laws of the communication of motion under such circumstances is one of the utmost complexity, and at present has been only resolved under very restricted conditions; enough, however, to verify principal facts, and establish leading points, in the doctrine of Acoustics. We shall be far from attempting to present here any thing approaching to a sketch of the profound geometrical researches which have been bestowed on this department of Physics, contenting ourselves with referring the reader for a knowledge of them to the various Memoirs of Euler, D. Bernouilli, Lagrange, Poisson, &c. See (1.) *Recherches sur la Nature et la Propagation du Son, par* L. de Lagrange, *Mém. Acad. Turin,* i. 247. (2.) Euler, *Recherches sur la Propagation des Ebranlemens dans un Milieu Elastique, Miscel. Turin,* ii. (3.) *Nouvelles Recherches sur la Propagation du Son, par* M. Lagrange, *Miscel. Turin,* ii. (4.) Euler, *De la Propagation du Son, Mém. Acad. Berlin,* 1759, p. 185, and *Supplement,* p. 210, and *Continuation,* p. 241. (5.) Euler, *Eclaircissemens plus détaillés sur la Propagation du Son et sur l'Echo, Mém. Acad. Berlin,* 1765, p. 335. (6.) Poisson, *Sur l'Intégration de quelques Equations Linéaires des Différens Partielles, Mèm. de l'Acad. Paris,* 1818, p. 121. (7.) Poisson, *Sur la Théorie du Son, Journal de l'Ecole Polytechn.* xiii. 319.: while we confine ourselves to just so much developement of the mathematical analysis of the subject as will suffice for the demonstration of the chief theoretical propositions we shall have occasion for in the sequel.

50. Propagation of Sound in air in one dimension. Fig. 4.

Let us then consider, as the simplest case, the propagation of Sound in a straight canal of equal bore throughout, filled with air or any other elastic fluid of equable density and elasticity, unacted on by gravity, and of which the transverse section is so small, and the sides so perfectly polished, that we may regard the motions of all particles in the same section as exactly similar; so that each section shall merely advance and recede in the pipe, without any lateral change of place of its constituent molecules *inter se.* Let A B (fig. 4) be such a pipe, and let any section of it, as A, be agitated by an external cause, with any arbitrary motion, *i. e.* one whose duration and extent, and whose velocity at every instant, shall be entirely dependent on the will, or, if we please, the caprice of an external operator sufficiently powerful to command it; and let us inquire how any other section whatever, situated at any assigned distance, x, from A, will move in consequence of this arbitrary motion of A.

51. Analysis of this case.

Let us then conceive, that, in general, the section or stratum of molecules $a\,a\,b\,b$, whose distance from the *initial place* A of the section A is represented by x, shall, after the lapse of any time t, have been transported into the situation $a\,\alpha\,\beta\,\beta$, at a distance $A\,a = y$ from the same fixed point A. Let x' x'', &c. be the distances of the next consecutive sections from the fixed point A, in their state of rest, and y', y'', &c. their distances after the lapse of *the same time* t. Then wil. $x' - x = d\,x$, $x'' - x' = d\,x'$, $x''' - x'' = d\,x''$, &c. be the thicknesses (supposed infinitely small) of these strata, or the spaces occupied by them (taking the area of the section for unity) in their quiescent state, and $y' - y = d\,y$, $y'' - y' = d\,y'$, $y''' - y'' = d\,y''$, &c. the same in their state of motion. Now as these strata were in contact at the origin of the motion, and are held together by the pressure of the surrounding fluid, they will remain in contact, and advance and recede along the pipe as one mass, only the space they will occupy at different points of their motion will be variable, according to the degree of condensation or dilatation they may have undergone in virtue of their motion itself. If, for instance, at any moment the hinder of them $d\,y$ be in the act of urging forward the next $d\,y'$, it will be condensed; if retreating, rarefied in comparison with the state of the preceding one $d\,y''$.

52. Expression of the acting forces.

Now any stratum of molecules $d\,y'$ interjacent between two others $d\,y$ and $d\,y''$ can only undergo a change in its velocity when urged by some force, and the only force which can urge it is the difference of pressures it may experience on its two faces by the difference (if any) of the elasticities of the adjacent strata $d\,y''$ and $d\,y$. If we can estimate this, the laws of Dynamics will enable us to express the consequent change of motion. To this end, then, let the elasticity of the air in its quiescent state be represented by E, which is a given quantity, and is measured by the weight of a column of mercury sustained by it, or by the length of a homogeneous column of air of the same density, whose weight shall suffice to keep it so compressed, or be equal to that of the column of mercury in the barometer. Then, since the elasticity of air is inversely as the space it occupies, (*cæteris paribus,*) the elasticity of the air when occupying the stratum $d\,x$: its elasticity when occupying $d\,y :: d\,y : d\,x$, and therefore the elasticity when occupying the space $d\,y = \mathrm{E} \,.\, \frac{d\,x}{d\,y}$. Similarly the elasticities of the air occupying $d\,y'$ and $d\,y''$ will be represented by $\mathrm{E} \,.\, \frac{d\,x'}{d\,y'}$ and $\mathrm{E} \,.\, \frac{d\,x''}{d\,y''}$. Hence the plane separating the strata $d\,y$ and $d\,y'$ will be pressed *forward* by the elasticity $\mathrm{E} \,.\, \frac{d\,x}{d\,y}$, and *backward* by $\mathrm{E} \,.\, \frac{d\,x'}{d\,y'}$. So that it will, on the whole, be urged forward by $-\,\mathrm{E}\left(\frac{d\,x'}{d\,y'} - \frac{d\,x}{d\,y}\right)$ that is, by $-\,\mathrm{E}\,d\,\frac{d\,x}{d\,y}$, the differentials being all on the supposition of t, the time being constant, and x and y only variable. Now, if we denote by H the length of a homogeneous column of air necessary to counterbalance the elasticity of the quiescent air, and by D its density, we have $\mathrm{H\,D}$ = its weight = the elasticity E, and $d\,x' \,.\, \mathrm{D}$ = the weight of the stratum $d\,x'$, which, substituting for D its value $\frac{\mathrm{E}}{\mathrm{H}}$, becomes $d\,x' \,.\, \frac{\mathrm{E}}{\mathrm{H}}$. Thus, then, the moving force $-\,\mathrm{E}\,d\,\frac{d\,x}{d\,y}$ is exerted in urging forward a weight $= d\,x' \,.\, \frac{\mathrm{E}}{\mathrm{H}}$, and is therefore equivalent to an accelerating force

$$-\,\mathrm{H} \,.\, \frac{d\left(\frac{d\,x}{d\,y}\right)}{d\,x'} = +\,\mathrm{H} \,.\left(\frac{d\,x}{d\,y}\right)^2 . \frac{d^2\,y}{d\,x^2},$$

regarding $d\,x$ as constant, or all the strata $d\,x$, $d\,x'$, $d\,x''$, &c. as originally equal.

53. Equation deduced.

Now the distance of the mass thus urged from the fixed point A, at the expiration of the time t, is y'. Hence, if we regard only the motion of the particle $d\,y'$ (or which comes to the same) of $d\,y$, which is in contact with it, we have by Dynamics

$$\left(\frac{d\,y}{d\,x}\right)^2 . \; \frac{d^2\,y}{d\,t^2} = 2\,g\,\mathrm{H} \,.\, \frac{d^2\,y}{d\,x^2}, \qquad (a)$$

where $2\,g = 9^{\mathrm{met.}}\,8088 = 32{\cdot}180$ British standard feet and gravity, for the unit of accelerating force, and in which equation t is expressed in mean solar seconds; and all linear quantities, such as H, x, y, in metres or feet, according as we take the metre or foot as the unit of linear measure.

54. Limitation in the case of Sound.

This is, in fact, an equation of partial differentials, y being at once a function both of x the original distance of the stratum $d\,x$ from the origin of the motion, and of t the time elapsed. In its present form, simple as it appears, it is altogether intractable and incapable of integration. In fact, it embraces a class of dynamical problems of very great complexity; for it is evident that since no hypothesis has been made in any way limiting the extent of the excursions of the original or subsequent strata from their points of quiescence, this equation must contain the general expression of all possible motions of elastic fluids in narrow pipes, whether great, as when urged by pistons or driven by bellows, or small, as are the tremors which cause Sound. In the theory of Sound we suppose the agitations of each molecule so minute as not to move it sensibly from its point of rest. Experience confirms this. Sounds transmitted through a smoky or dusty atmosphere cause no visible motion in the smoke or floating dust, unless the source of Sound be so near as to produce a *wind*, which, however, is always insensible at a very moderate distance.

55. Simplification of the final equation.

If we introduce this condition, the equation (a) admits of integration; for the whole amount of motion of each molecule being extremely minute, their differences for consecutive molecules, or the amount of the rarefactions and condensations undergone, must be much more so. Hence the value of $\frac{d\,y}{d\,x}$, which expresses the ratio of the condensation of the stratum $d\,y$ in motion and in rest, may be regarded as equal to unity, and the equation becomes simply,

$$\frac{d^2\,y}{d\,t^2} = a^2\,\frac{d^2\,y}{d\,x^2}, \quad \text{where } a = \sqrt{2\,g\,\mathrm{H}}\,; \qquad (b)$$

which is the equation of Sound regarded as propagated in one dimension, that of length, only; or, as prevented from spreading laterally by a pipe.

56. Its integration.

The complete integral of this equation is well known to be

$$y = \mathrm{F}(x + a\,t) + f\,(x - a\,t), \qquad (c)$$

where F and f denote arbitrary functions of the quantities within the parenthesis, and which must be determined by a consideration of the initial state of the fluid, or by the nature of the motion originally communicated to its molecules.

57. Determination of the arbitrary functions.

Let us then suppose, that, at the commencement of the motion, we have impressed on each section of the fluid, along its whole extent, any arbitrary velocities and condensations, by any means whatever, so as to comprehend in our investigation all possible varieties of initial motion, whether expressible by regular analytical functions, or depending on no regular law whatever. It is manifest that these conditions will be expressed by assuming arbitrary functions of x, such as $\phi\,(x)$ and $\psi\,(x)$ for the *initial* values of the two partial differentials $\frac{d\,y}{d\,t}$ and $\frac{d\,y}{d\,x}$, whereof the former represents in all cases the velocity (v) of a particle which would be at the distance x from the origin of the coordinates in the state of equilibrium, and the latter the linear extent (e) of that particle compared with its original extent, to which its density and elasticity are reciprocally proportional. Now, differentiating (c) we get for the general values of v and e

$$v = \frac{d\,y}{d\,t} = a\,\{\,\mathrm{F}'(x + a\,t) - f'\,(x - a\,t)\,\}\,; \qquad (d)$$

$$e = \frac{d\,y}{d\,x} = \mathrm{F}'(x + a\,t) + f'\,(x - a\,t)\,; \qquad (e)$$

consequently their initial values, making $t = 0$, will be

$$\phi\,(x) = a\,.\,\{\,\mathrm{F}'\,(x) - f'\,(x)\,\}$$
$$\psi\,(x) = \mathrm{F}'\,(x) + f'\,(x),$$

whence we get immediately

$$\mathrm{F}'\,(x) = \frac{1}{2\,a}\,\{\,a\,\psi\,(x) + \phi\,(x)\,\}\,;\; f'\,(x) = \frac{1}{2\,a}\,\{\,a\,\psi\,(x) - \phi\,(x)\,\}\,; \qquad (f)$$

and multiplying by $d\,x$ and integrating

$$\mathrm{F}\,(x) = \frac{1}{2\,a}\int\{\,a\,\psi\,(x) + \phi\,(x)\,\}\,d\,x\,; \qquad f\,(x) = \frac{1}{2\,a}\int\{\,a\,\psi\,(x) - \phi\,(x)\,\}\,d\,x\,;$$

and thus the forms of the functions F and f become known when those of ϕ and ψ are given.

58. Expression of the state of any molecule at any instant.

The question of the propagation of Sound, however, does not require us to concern ourselves with these functions, as a knowledge of the actual velocity aud density of any molecule at any instant is sufficient for our purpose. Substituting then in (d) and (e) for F′ and f', the forms corresponding in ϕ and ψ, we get

$$v = \frac{d\,y}{d\,t} = \frac{a}{2}\,\{\,\psi\,(x + a\,t) - \psi\,(x - a\,t)\,\} + \frac{1}{2}\,\{\,\phi\,(x + a\,t) + \phi\,(x - a\,t)\,\}\,; \qquad (g)$$

$$e = \frac{d\,y}{d\,x} = \frac{1}{2}\,\{\,\psi\,(x + a\,t) + \psi\,(x - a\,t)\,\} + \frac{1}{2\,a}\,\{\,\phi\,(x + a\,t) - \phi\,(x - a\,t)\,\}\,; \qquad (h)$$

or, as it may also be written,

$$v = \frac{1}{2}\,\{\,\phi\,(x + a\,t) + a\,\psi\,(x + a\,t)\,\} + \frac{1}{2}\,\{\,\phi\,(x - a\,t) - a\,\psi\,(x - a\,t)\,\}\,; \qquad (i)$$

$$e = \frac{1}{2\,a}\,\{\,\phi\,(x + a\,t) + a\,\psi\,(x + a\,t)\,\} - \frac{1}{2\,a}\,\{\,\phi\,(x - a\,t) - a\,\psi\,(x - a\,t)\,\}\,. \qquad (j)$$

59. These are essentially the same expressions with those given by Euler in his Paper on the Propagation of Sound, in the *Berlin Memoirs for* 1759, and by Poisson in his elaborate Memoir on the Motion of Elastic Fluids in Pipes, and on the theory of Wind Instruments, and they comprise the whole theory of the linear propagation of Sound. But before we proceed to the interpretation of their meaning in particular cases, we have a few remarks to make on their general form.

60. Remarks on these expressions.

And, first, it is evident, that since the variable quantity x enters into all the terms both of v and e under the functional characteristics, these quantities, regarded as functions of t, are modified essentially by the value of x, which may be regarded as a parameter, or constant element in the composition of the functions expressing the nature of the motion of any assigned molecule. If only $x + a\,t$, or only $x - a\,t$, separately entered under the characteristics, since $x + a\,t = a\left(t + \frac{x}{a}\right)$ and $x - a\,t = -\,a\left(t - \frac{x}{a}\right)$ the variation of x would only vary the *origin* of t; and the motions of all the successive molecules would be performed according to the same laws, only commencing at a different epoch for each molecule; but, as both these quantities are involved, that will not be universally the case. Consequently, in general, it appears that the undulation, or pulse, as it is propagated onward, becomes modified essentially in its quality by the distance it has passed over, it is no longer *the same sound*, *i. e.* not identical with what would be produced by shifting the initial stratum forward. Its velocity, intensity, and pitch, it is true, will remain (as we shall see) unaltered; but its *quality*, its mode of action on the ear, (which must be differently affected by changes in the nature of the impulse made on it,) will undergo a change. This establishes an essential difference between a Sound wave and such a wave as we took for an illustration in Art. 45, where every point was in succession agitated by the same *identical* motion.

61 Inaccuracies in Newton's theory of Sound.

Consequently every theory of Sound in which it is assumed that the several particles in a sounding column are all in succession agitated alike, is defective. This is the case with Newton's doctrine of the propagation of Sound as delivered in the 47th proposition of the 2nd book of the *Principia*, and, were there no other objection against it, would suffice to vitiate the whole. This, and other unsatisfactory points in the celebrated theory alluded to, were first distinctly perceived and pointed out by Lagrange, in the first volume of the *Turin Miscellanies*, and an exact and rigorous investigation substituted in its place, in which the sounding column is regarded as consisting of a series of finite, insulated particles, mutually repelling each other; a mode of conception which leads, by a very complicated analysis, to the same results with that above stated, but which has the advantage of setting in a distinct light the internal mechanism, if we may so term it, by which Sound is propagated, and to which we therefore willingly refer the reader.

62. Moreover, since by differentiating the equation (*d*) we get

$$\frac{d^2 y}{d t^2} = a^2 \{ \mathrm{F}''(x + a t) + f''(x - a t) \},$$

this will be proportional to the accelerating force acting on the molecule. It is therefore by no means universally proportional to $y - x$, the distance of the molecule from its point of rest; and therefore another assumption on which the Newtonian doctrine of Sound rests, *viz.* that the motion of each molecule necessarily follows the law of a vibrating pendulum, is equally destitute of foundation. In fact, Cramer had shown, before the examination of Lagrange, that any other law of molecular motion might be substituted in Newton's enunciation of his general proposition, and the demonstration would be equally conclusive, and the resulting velocity of Sound the same.

63. Case of a very small initial disturbance.

Let us now descend more into particulars; and, first, let us suppose the initial state of the fluid to consist in a general repose of the whole of an infinitely extended column, except a very small portion at A the origin of the coordinates, which we will suppose agitated with any arbitrary motion. This is, in fact, the simplest case of the production of Sound; the initial disturbance of the air being always confined within extremely small limits compared to the distances to which the Sound is propagated. Let us then conceive the initial disturbance to take place over a minute length $2\,\mathrm{a}$ of the column, whose middle we will suppose to be in the origin of the x. This amounts to supposing $\phi(x) = 0$, and $\psi(x) = 1$, for every value of x not comprised within the limits $x = -\mathrm{a}$ and $x = +\mathrm{a}$, admitting them to have any arbitrary values between these limits.

64. Propagation of a single initial disturbance, beginning and terminating suddenly.

If we suppose now t to be less than $\frac{x - \mathrm{a}}{a}$, and regard at first what happens only on the positive side of the origin of the x, since $t < \frac{x - \mathrm{a}}{a}$ we have $a t < x - \mathrm{a}$, and therefore $x - a t > + \mathrm{a}$, and, *à fortiori*, $x + a t > + \mathrm{a}$, consequently for all values of t less than $\frac{x - \mathrm{a}}{a}$ we have $\phi(x - a t) = 0$, $\phi(x + a t) = 0$; $\psi(x - a t) = \psi(x + a t) = 1$; and therefore for all values of t less than $\frac{x - a}{a}$ we have $v = 0$, and $e = 1$. Consequently the molecule at the distance x from the origin of the coordinates, will remain at rest and uncondensed, or expanded, so long as t remains less than $\frac{x - \mathrm{a}}{a}$; that is, for a time proportional to the distance from the nearest point of the initial disturbance. But the moment t has attained this limit, $\phi(x \pm a t)$ will have finite values, and $\psi(x \pm a t)$ values differing from unity, and v and e will consequently have such. The particle then will begin to move, and to undergo a change of density, and will continue to do so till $t = \frac{x + \mathrm{a}}{a}$. At this limit we have $x - a t = - \mathrm{a}$, $x + a t = 2 a t - \mathrm{a} = 2(x + \mathrm{a}) - \mathrm{a} = 2x + \mathrm{a}$, and consequently $x + a t > + \mathrm{a}$. Hence at this limit we have again $\phi(x - at) = \phi(x + a t) = 0$, and $\psi(x - a t) = \psi(x + a t) = 1$, and the motion and condensation of the particle will cease; and will not be resumed afterwards, because the supposition $t > \frac{x + \mathrm{a}}{a}$ gives $x - a t < - \mathrm{a}$, and $x + a t > 2x + \mathrm{a}$, and, *à fortiori*, $> + \mathrm{a}$, so that the functions retain their values 0 and 1 from this moment for ever.

65. Velocity of Sound uniform.

Thus we see that the molecule distant by x from the origin of the coordinates will remain at rest for a certain time $t = \frac{x - \mathrm{a}}{a}$, will then begin to move, and continue moving, during a time equal to $\frac{x + \mathrm{a}}{a} - \frac{x - \mathrm{a}}{a} = \frac{2\,\mathrm{a}}{a}$, or till $t = \frac{x + \mathrm{a}}{a}$, and will then return to a state of permanent rest. A similar reasoning will apply for negative values of x. Hence if we consider any two molecules at distances x, x' from A, we see that the more distant will commence and terminate its motion later than the nearer, by an interval of time $= \frac{x' - x}{a}$. This then is the time required for the propagation of the impulse, or Sound, over the intermediate space $x' - x$, and being proportional to that space, the velocity of propagation must be uniform, and must be represented by the quantity $a \left(= \frac{x' - x}{t' - t} = \frac{\text{space}}{\text{time}} \right)$. Hence it follows that *the velocity of Sound is uniform,—is independent of the nature, extent, and intensity of the primitive disturbance, (for the arbitrary functions do not enter it,) and is expressed by the quantity we have called* a, *that is* $\sqrt{2 g \mathrm{H}}$.

Its expression.

66. First approximation to its numerical value.

Let us reduce this to numbers, in order to compare theory with observation. To this end, if we call Δ the density of mercury, h the height of the mercury in a barometer exposed to the same pressure as the sounding column, and D the density of the air in it, we have for the height of a homogeneous column of such air capable of counterbalancing the elasticity of the sounding fluid, the following value

$$\mathrm{H} = h \,.\, \frac{\Delta}{\mathrm{D}};$$

and, calling V the velocity of Sound, we should have

$$\mathrm{V} = \sqrt{2 g h \,.\, \frac{\Delta}{\mathrm{D}}}.$$

Now, at the freezing temperature, and in a mean state of barometric pressure, we have, according to Biot, $h = 0^{\text{met.}}.76$; $2g = 9^{\text{met.}}.8088$; and $\frac{\Delta}{\mathrm{D}} = 10463$; so that we obtain, by executing the numerical operations, $\mathrm{V} = 279^{\text{met.}}.29 = 916^{\text{feet.}}.322$.

67. Great difference between theory and experiments on the assumed hypotheses.

Various attempts to account for it.

The actual value of V obtained by experiment is, as we have seen, 1089.42. The difference, 173 feet, is nearly one-sixth of the whole amount; a discrepancy far too great to be attributed to any inaccuracy in the determination of the data, which are all of the utmost precision. It is evident, then, that there is something radically insufficient in the theory, as above delivered; and, accordingly, Geometers for a long while endeavoured to account for it on various suppositions. Newton, who, by a singularly happy coincidence, which certainly deserves to be called a divination, had, from a theory totally inapplicable in all its points, elicited the correct expression $\sqrt{2 g \mathrm{H}}$ above demonstrated, for the velocity of Sound, and who immediately encountered this difficulty on deducing its numerical value, endeavours to account for the deficient 173 feet by supposing the molecules of the air to be actual spherical solids of a certain diameter, ($\frac{173}{916}$ of the interval between them,) and that the Sound is propagated through them *instanter*. It is needless to comment on this explanation. Lagrange treats the whole matter lightly, and seems inclined to attribute the deviation of fact from theory to erroneous data; in other words, dissembling the difficulty, which Euler, on the contrary, broadly acknowledged; and considered that it might possibly arise from an incorrectness of analysis, in assuming the factor $\left(\frac{dy}{dx}\right)^2 = 1$ in the equation (a) Art 53, previous to integration. The true explanation was reserved for the sagacity of Laplace. But before we state it, it will be necessary to consider what will be the effect of variations of temperature and pressure on the velocity, according to the principles already laid down, and the formula arrived at.

68. Effect of variations of temperature and pressure on the velocity of Sound.

With regard to an increase of pressure, its effect is to increase the density of the air; but since at the same time it increases its elasticity, and in exactly the same ratio; the mass to be moved, and the moving force, are increased alike, and therefore the accelerating force remains unaltered. The velocity, therefore, ought to undergo no change by this alteration. On the other hand, an increase of temperature, under a constant pressure, tends to dilate the air, and either renders it more elastic in the same space, or more rare with the same elasticity. Hence, on a variation of temperature, the moving force remains unaltered, while the mass moved decreases, and therefore an acceleration in all the resulting motions must arise. The velocity of Sound then ought to be greater in warm than in cold air, *cæteris paribus*. These two conclusions are both amply confirmed by experiment. They agree too with the formula above stated; for, if we denote by (h) the *mean* height of the mercury in the barometer ($0^{\text{met.}}.76$), and by (D) the density of air under this pressure at the freezing temperature, since, by the experiments of Gay Lussac, air expands 0·00375 of its volume by every degree *centigrade* of increase of temperature, its density under the pressure (h) at any other temperature $+ \tau^\circ$ (centig.) will be $\frac{(\mathrm{D})}{1 + \tau \,.\, 0{\cdot}00375}$, and under the pressure h it will be $\frac{h}{(h)} \times \frac{(\mathrm{D})}{1 + \tau \,.\, 0{\cdot}00375} = \mathrm{D}$; consequently the expression (Art. 66) for the velocity becomes

$$\mathrm{V} = \sqrt{2 g (h) \,.\, \frac{\Delta}{(\mathrm{D})} \times (1 + \tau \,.\, 0{\cdot}00375)}.$$

Now, if we call (V) the velocity under the mean pressure (h), and at the freezing point, this gives

$$(\mathrm{V}) = \sqrt{2 g (h) \,.\, \frac{\Delta}{(\mathrm{D})}},$$

and therefore $$V = (V) . \sqrt{1 + \tau . 0{\cdot}00375} = (V) \{ 1 + \tau . 0{\cdot}001875 \},$$
or if τ be expressed in degrees of Fahrenheit's scale,
$$V = (V) \{ 1 + \tau . 0{\cdot}001042 \};$$
which shows, first, that the velocity is independent of the pressure, since h is not contained in its expression; and that, secondly, τ increases by very nearly the 0·001875 part of its whole quantity for every degree centigrade, or $\frac{5}{9} \times 0{\cdot}001875 = 0{\cdot}001042$ for every degree Fahrenheit above the freezing point, that is in feet 1·136, (see Art. 17.) and decreases by the same quantity for each degree below freezing.

69.
Laplace's explanation of the anomaly above mentioned.

The law of Mariotte, which makes the elastic force of the air proportional to its density, and which has been employed in estimating the elasticity with which each molecule of the aerial column resists condensation, and transmits it to its neighbour, assumes that the temperature of the whole mass of air is alike, and undergoes no change in the act of condensation, and is therefore only true of masses of air which, after compression, are of the same temperature as before. But it is an ascertained fact, that air and all elastic gaseous fluids give out heat in the act of compression, *i. e.* actually become *hotter*, a part of their latent heat being developed, and acting to raise their temperature. This is rendered evident in the violent and sudden condensation of air by a tight-fitting piston in a cylinder closed at the end. The cylinder, if of metal, becomes strongly heated; and if a piece of tinder be enclosed, on withdrawing the piston it is found to have taken fire; thus proving that a heat, not merely trifling, but actually that of ignition, has been excited, of at least 1000° of Fahrenheit's scale. Now when we consider how small the mass of air in such an experiment is, compared with that of the including vessel, which rapidly carries off the heat generated, it is evident that if air by any cause could be compressed *to the same degree* without contact of any other body, a very enormous heat would be generated in it. It would, therefore, resist the pressure much more than if cold; and, consequently, would require a much more powerful force to bring it into that state of condensation than, according to Marriotte's law, would be necessary.

Heat developed in air in act of compression

70.
Influence of this cause in the propagation of Sound.

Air, then, when suddenly condensed, and out of contact with conducting bodies, resists pressure more (*i. e.* requires a greater force to condense it equally) than when slowly condensed, and the heat developed carried off by the contact of massive bodies of its original temperature. In other words, it is under such circumstances *more elastic*, and our analytical expression for its elasticity must be modified accordingly. In fact, the condensation of the aerial molecules in the production of Sound is precisely performed under the circumstances most favourable to give this cause its full influence; the condensations being so momentary that there is no time for any heat to escape by radiation; and the condensed air being in contact with nothing but air, *differing infinitesimally from its own temperature;* so that conduction is out of the question. Let us see now how this will affect the matter in hand.

71.
Modification of the analysis and formulæ required by it.

It was assumed in Art. 35, that the elasticity of the air occupying the space $d\,x$, or (E) : its elasticity when occupying $d\,y :: d\,y : d\,x$. But, in fact, the varied temperature being taken into account, the latter ratio should have stood $:: d\,y\,(1 + a\,\tau) : d\,x\,(1 + a\,\tau')$, where a denotes the coefficient 0·00375, and τ and τ' the original and altered temperatures in centrigrade degrees. Hence in place of $E . \frac{d\,x}{d\,y}$ we must have $E . \frac{d\,x}{d\,y} . \frac{1 + a\,\tau'}{1 + a\,\tau}$, that is, $E . \frac{d\,x}{d\,y} \{ 1 + a\,(\tau' - \tau) \}$, for the elasticity of the molecule of air when occupying the space $d\,y$, because, the condensations being all along supposed exceedingly small, τ' differs from τ only by a quantity of the same order as the condensations; so that $(\tau' - \tau)^2$ and its higher powers may be neglected.

72.
Analysis.

Now, whatever may be the law according to which the temperature of a mass of air is increased by a sudden diminution of its volume, it is obvious that for very small condensations, such as those considered in the theory of Sound, the rise of temperature will be proportional to the increase of density; because, the quantity of latent heat having sustained only a very minute diminution, by a given extremely small condensation, a repetition of the same condensation will develope a quantity of heat falling short of the first only by a quantity of the second order; so that, neglecting such quantities, double the condensation will develope double the heat, and so in proportion. Hence we must have $\tau' - \tau = k \left\{ 1 - \frac{d\,y}{d\,x} \right\}$ where k is a constant coefficient, whose magnitude may become known either by direct experiment, or by the very phenomena under consideration. Substituting this for $\tau' - \tau$, we get, for the elasticity of the condensed molecule,
$$E . \frac{d\,x}{d\,y} \left\{ 1 + k\,a \left(1 - \frac{d\,y}{d\,x} \right) \right\} = E\,(1 + k\,a) . \frac{d\,x}{d\,y} - k\,a\,E.$$
And the difference of elasticities on either side of the plane separating the molecules $d\,y$ and $d\,y'$, instead of being, as in (Art. 35.) $- E . d\,\frac{d\,x}{d\,y}$, will be now represented by $- d \left\{ E\,(1 + k\,a)\,\frac{d\,x}{d\,y} - k\,a\,E \right\}$, that is, by
$$- E\,(1 + k\,a) . d\,\frac{d\,x}{d\,y}.$$

This differs from the expression originally obtained only by the constant factor $(1 + k\,a)$. Without, therefore, going again through all the foregoing analysis, we see at once that the general equations of Sound will be precisely as before, writing only $(1 + k\,a) . H$ for H throughout; and, therefore, if instead of putting, as before, 73

Final and exact expression of the equation and velocity of Sound.

$a = \sqrt{2gH}$, we put $a = \sqrt{2gH(1 + k\alpha)} = \sqrt{2gH.K}$; when $K = 1 + k\alpha$ the equation (a) will become

$$\left(\frac{dy}{dx}\right)^2 . \frac{d^2y}{dt^2} = a^2 . \frac{d^2y}{dx^2};$$

and all the other equations will remain unaltered, and the velocity of Sound on this new hypothesis will be expressed by the new value ascribed to a, that is, by

$$V = \sqrt{2gH(1 + \alpha k)}$$
$$= \sqrt{2g(h) . \frac{\Delta}{(D)} K (1 + \alpha\tau)}$$

where $\alpha = 0·00375$.

74. Value of K how determinable.

The actual numerical value of the constant coefficient K may be determined, as we have before said, in two ways; either by direct experiment on the increase of temperature developed in a given volume of air by a given condensation, or by a comparison of the formula to which we have arrived with the known velocity of Sound. As we have already observed, however, the circumstances under which Sound is propagated are far more favourable to the free and full production of the whole effect of the cause in question than those of any experiments in close vessels. We must not, therefore, be surprised, if the value of K as derived from such experiments should differ materially from its value deduced from the velocity of Sound; nor *vice versâ*, if the observed velocity of Sound should differ materially from that obtained by calculation, from an experimental value of K. It is sufficient, in a philosophic point of view, to have pointed out a really existing cause, a *vera causa*, which *must* act to increase the velocity, and is fully adequate to do so to the extent observed.

75. Determined from the velocity of Sound itself.

We have seen that the numerical value of V neglecting K is equal to 916·322 feet. The observed value on the other hand, is 1089·42. Hence we have the following equation for determining K and k,

$$1089·42 = 916·322 \times \sqrt{1 + k . 0·00375} = 916·322 \times \sqrt{K},$$

whence we obtain
$$K = \left(\frac{1089·42}{916·32}\right)^2 = 1·4132,$$

and
$$k = \frac{1}{0·00375} \left\{ \left(\frac{1089·42}{916·32}\right)^2 - 1 \right\} = 110·26.$$

Difficulty of its direct determination.

The actual amount of heat given out by a given amount of condensation is not an element very easily or exactly determinable by direct experiment with thermometers. If a common mercurial thermometer be enclosed in a receiver, and the air suddenly compressed, the thermometer, it is true, rises; but the amount of its rise is evidently far inferior to the actual increase of temperature; for, first, its mass is enormously greater than that of the air *immediately* in contact with it; secondly, it is brought into contact successively with an unknown, and, no doubt, a variable quantity in different experiments, by the effect of circulation; thirdly, the vessel used carries off by far the greater part of the heat, and one which we have no means of estimating. It is accordingly found that by increasing the sensibility of the thermometer, by extending its surface compared to its mass, higher and higher degrees of temperature are indicated for the same condensation; and highest of all when the delicate pyrometer of Breguet is used, which consists of two extremely thin strips of platina and palladium soldered together over their whole surface, and coiled up in a spiral, which twists and untwists by the different expansions of the metals constituting its inner and outer face. Still, however, though almost all surface, the materials of which this instrument consists are so infinitely denser than air, that its indications must fall far short of the truth.

76. Experiment of Clement and Desormes.

Another very ingenious method has been practised by Messrs. Clement and Desormes. (*Journal de Physique*, November, 1819, p. 334.) Suppose we have any quantity of air enclosed in a receiver communicating, first, with an air-pump, by a valvular orifice, (A); second, with the upper part of a barometer tube containing mercury, whose height therefore measures the elasticity of the air in the receiver by its depression below the barometric level of the external atmosphere; thirdly, with the external air, by a stopcock, or valve, (B,) so large that the pressure within may be instantaneously restored to an equilibrium with that without, on opening it. Let the whole apparatus be at the temperature of the atmosphere, (τ,) and suppose the valve (B) open, then will the internal elasticity, or pressure, (P,) be equal to that without, and also the density (D.) Close the valve B, and open A, and, by means of the air-pump, exhaust a small portion of the air; and, again closing the valve A, let the apparatus remain at rest till the whole has attained the temperature τ of the atmosphere. In this state let the internal pressure be observed by the barometer, which call P'; and D', the density, will, of course, be equal to $D . \frac{P'}{P}$, and is therefore known. Now suddenly open the valve B. The external air will rush in and restore the equilibrium. The moment this is done (which will be known by the cessation of the inward current) let the valve B be closed. It will then be found that the internal temperature is raised by the condensation thus effected, and has become τ'; and the increase of temperature $\tau' - \tau$ may be measured by a delicate thermometer, and that with the more precision the greater the capacity of the receiver. But it will be much more exactly measured by the following process, which, in fact, amounts to making the receiver itself an *air thermometer*. At the moment of closing the valve the internal pressure is, of course, P. But as the air cools, its elasticity diminishes, and, being cut off from a fresh supply from without, the mercury will rise in the barometer tube till the whole of the heat evolved is dissipated. Let the internal pressure, then, be again observed when this state is attained, and call it P'', then will the corresponding density, or D'', be equal to $D \cdot \frac{P''}{P}$. It is required from these data (P, P', P'', being given by observation) to deduce the value of $\tau' - \tau$ and the coefficient k.

77. Analysis of this experiment.

Now, this is easy; for, first, since in the final state of the receiver the density is D'' sustaining a pressure P'' at a temperature τ; therefore, the same quantity of air in the same space, raised to the temperature τ', would sustain a pressure $P'' \times \{ 1 + a(\tau' - \tau) \}$ where $a = 0{\cdot}00375$, τ being in centigrade degrees, its density remaining D''. But at the moment of closing the valve A, the temperature was τ', and the pressure simply P, we have, therefore,

$$P = P''\{1 + a(\tau' - \tau)\}, \text{ whence } \tau' - \tau = \frac{P - P''}{a P''}.$$

Now, secondly, this is the elevation of temperature due to the sudden transition of the air from the density D' to the density D'', by the introduction of that portion of external air which rushed in on opening the valve. Calling 1 the capacity of the receiver, $1 \times D' = D'$ expresses the quantity of air in it before the valve was opened, and $1 \times D''$ or D'' the quantity after, so that $D'' - D'$ expresses the quantity of air admitted. Its density before admission being D, and afterwards D'', it had undergone a dilatation equal to $1 - \frac{D''}{D}$, and therefore *its* temperature had *diminished* by an amount represented by $k\left(1 - \frac{D''}{D}\right)$. On the other hand, the quantity of air in the receiver before opening the valve was $1 \times D' = D'$, and this quantity having changed its density suddenly from D' to D'', must have undergone an *elevation* of temperature represented by $k\left(1 - \frac{D'}{D''}\right)$. These two masses of air, the one cooled by dilatation, the other heated by condensation, became suddenly mixed, and therefore must have undergone a mean rise of temperature $= \dfrac{\text{sum of products of masses and changes of temp.}}{\text{sum of masses}}$

and, consequently,

$$\text{mean elevation of temperature} = \frac{\left\{D'\left(1 - \frac{D'}{D''}\right) - (D'' - D')\left(1 - \frac{D''}{D}\right)\right\}k}{D' + D'' - D' = D''},$$

$$= \frac{D'' - D'}{D''}\left\{\frac{D'}{D''} - \frac{D - D''}{D}\right\}k = \frac{D'' - D'}{D''}\left\{\frac{D'}{D''} + \frac{D''}{D} - 1\right\}k,$$

$$= \left(1 - \frac{D'}{D''}\right)\left\{\frac{D''}{D} - \left(1 - \frac{D'}{D''}\right)\right\}k = k\left\{\frac{D''}{D}\left(1 - \frac{D'}{D''}\right) - \left(1 - \frac{D'}{D''}\right)^2\right\}.$$

But we have

$$\frac{D''}{D} = \frac{P''}{P}, \text{ and } \frac{D'}{D} = \frac{P'}{P}, \text{ so that } \frac{D'}{D''} = \frac{P'}{P''},$$

and therefore substituting, we find for the value of the above expression, or $\tau' - \tau$,

$$k\left\{\frac{P''}{P}\left(1 - \frac{P'}{P''}\right) - \left(1 - \frac{P'}{P''}\right)^2\right\} = k \cdot \frac{P'' - P'}{P}\left\{1 - \frac{P(P'' - P')}{P''^2}\right\}.$$

Value of k expressed.

If we suppose the changes of pressure sufficiently small to allow of their squares being neglected, the value of $\tau' - \tau$ is reduced to $k \cdot \frac{P''}{P}\left(1 - \frac{P'}{P''}\right) = k \cdot \frac{P'' - P'}{P}$. Equating this to $\frac{P - P''}{a P''}$, the previously determined value of $\tau' - \tau$, we get

$$k = \frac{1}{a} \cdot \frac{P - P''}{P'' - P'} \cdot \frac{P}{P''}; \qquad k a = \frac{P(P - P'')}{P''(P'' - P')}.$$

78. Numerical computation.

In an experiment of Messrs. Clement and Desormes, on which M. Poisson has grounded his romputation of the theoretical velocity of Sound, the values of P, P', P'' were

$$P = 0^{m}{\cdot}7665; \qquad P - P' = 0^{m}{\cdot}01381; \qquad P - P'' = 0^{m}{\cdot}00361;$$

and, consequently,

$$P'' - P' = 0{\cdot}01020,$$

which gives, by the approximate formula,

$$k a = 0{\cdot}3492, \qquad \text{and } 1 + k a = 1{\cdot}3492;$$

whence the velocity, at a mean pressure and freezing temperature, comes out

$$916^{\text{feet}}{\cdot}322 \cdot \sqrt{1{\cdot}3492} = 1064{\cdot}35,$$

which falls short of the actually observed velocity only by about 25 feet. If the rigorous value of $k a$ be employed, the deficiency is rather less, the velocity coming out 1066·2. In this experiment, the time occupied by the intromission of the air was about half a second; the whole elevation of temperature, computed from the formula $\tau' - \tau = \frac{P - P''}{a\,P''}$, must have been 1°·321 centig. (= 2°·378 Fahr.) M. Poisson has shown (*Annales de Chim*. xxiii. 1823, p. 11) that an absorption of $\frac{1}{3}$ of a degree (cent.) by the receiver, which might very well happen, would completely reconcile the observed and theoretical velocities. Laplace, calculating on the experiments of Messrs. Welter and Gay Lussac, has, since, obtained a still nearer approximation to the theoretical velocity, the difference amounting only to about 3 metres. In inquiries of such delicacy, and where the effects of minute errors of experiment become so much magnified, it seems hardly candid to desire a more perfect coincidence.

79. Another mode of expressing the effect of the developed heat on the velocity of Sound.

Laplace, guided by peculiar theoretical considerations respecting the constitution of gaseous fluids, has been induced to put the foregoing expression for the velocity of Sound under a somewhat different form. Let K denote the ratio of the specific heat of air under a constant *pressure* to its specific heat if retained at a constant *density;* that is, a fraction whose numerator is the quantity of heat requisite to raise a given mass of air 1° in temperature *under a constant pressure,* (its volume being permitted to increase,) and whose denominator is the quantity necessary to raise it 1° *in a constant volume,* or when so confined as not to dilate. Then will the velocity of Sound be

$$V = \sqrt{2\,g\,(h)\,.\,\frac{\Delta}{(D)}\,(1 + a\,\tau)\,.\,K.}$$

To show this, let Q and q be the quantities of heat above mentioned. It is evident, first, that when forcibly prevented from expanding, and thereby absorbing heat and rendering it latent, a less *quantity* of heat will suffice to raise the temperature of a given mass of air any given quantity, as 1°, than if unconfined. In fact, suppose it heated 1°, and allowed *meanwhile* to dilate, so that the temperature of the *dilated* air shall be 1° above its primitive state, then, if compressed back into its original volume, the whole quantity of heat developed by the condensation will be employed in raising the temperature still higher. If then the quantity Q of caloric raise the temperature 1° under a given *pressure,* it will raise it more than 1° when confined to a given *volume,* by the whole amount of temperature due to a compression equal to its dilatation in the former case. Suppose the initial temperature freezing, then if $a = 0{\cdot}00375$, an increase of temperature of 1° cent. will produce, under a constant pressure, a dilatation $= a$, and the volume from 1 will become $1 + a$. Let the air so dilated and raised in temperature be compressed back to its former volume, then will its temperature be further increased by $k\,a$, k denoting as before; so that the quantity of caloric Q will have ultimately produced a rise of temperature $= 1 + k\,a$, under a constant volume; and therefore a quantity $= \frac{Q}{1 + k\,a}$ only would be required to raise it 1°. Hence $q = \frac{Q}{1 + k\,a}$, and $1 + k\,a = \frac{Q}{q} = K$. This demonstration assumes, as an axiom, that the temperature produced by the introduction of the same quantity of caloric is the same, whether it be introduced into air confined in a given space, or into air allowed to expand freely, and then forcibly compressed back; which it evidently is, since the heat given out by the compression must of necessity exactly equal that absorbed and rendered latent in the act of expansion.

§ II. *Of the Linear Propagation of Sound in Gases and Vapours.*

80. Interpretation of the formula in the case of gases and vapours.

The analysis by which we have in the foregoing articles determined the laws and velocity of the propagation of Sound in air, applies equally, *mutatis mutandis,* to its propagation in all permanently elastic fluids, and in vapours, in so far as their properties are the same as those of gases. The formula so often referred to then

$$V = \sqrt{2\,g\,(h)\,.\,\frac{\Delta}{(D)}\,.\,K\,.\,(1 + a\,\tau)}$$

expresses the velocity of Sound in all such media, provided for (D) we write instead of the density of atmospheric air that of the gas at the freezing temperature, and under the mean pressure (*h*). In the case of vapours we must suppose in calculating the value of (D) that they follow the law of gases in their condensation, and that no portion of them undergoes a change of state to a liquid, by reduction to the standard temperature and pressure. Suppose, then, the specific gravity of atmospheric air to be denoted by s, and that of any gas or vapour under the same temperature and pressure by s'; then if V and V′ be the velocities of Sound in air, and in the gas or vapour, we have

$$V = \sqrt{2\,g\,(h)\,.\,\frac{\Delta}{s}\,K\,(1 + a\,\tau)}, \qquad V' = \sqrt{2\,g\,(h)\,.\,\frac{\Delta}{s'}\,K'\,(1 + a\,\tau)},$$

because (see PNEUMATICS, HEAT) the law of dilatation, or the value of a, is alike in all. Consequently, we have

$$\frac{V'}{V} = \sqrt{\frac{s}{s'}\,.\,\frac{K'}{K}},$$

or
$$V' : V :: \sqrt{\frac{K'}{s'}} : \sqrt{\frac{K}{s}};$$
whence the ratios of $s' : s$ and of $K' : K$ being known, the ratio of the velocities is also known, being, *cæteris paribus*, in the inverse subduplicate ratio of the specific gravities.

81. How comparable with experiment.

To compare this with experiment directly is impracticable, as no column of any gas but atmospheric air can be obtained of sufficient length and purity to determine the velocity of Sound in it by direct measure. Indirectly, however, the comparison may be performed by comparing the Sounds of one and the same organ-pipe, filled with the gases to be compared, successively, or by other means of a similar kind, of which more hereafter. (See INDEX, under the heads *Gases*, *Vapours*, Sounds of *Pipes*.)

82. Velocity of Sound in various media.

The following Table exhibits the Velocities of Sound, as deduced from theory, and compared with experiments instituted by M. Van Rees, in conjunction with Messrs. Frameyer and Moll.

Gas, or Vapour.		Velocity of Sound, reduced to 0° R. (freezing.)	Velocity of Sound, reduced to 0° R.	Velocity assigned by Chladni, *Acoustics*, p. 274.
		Theory.	Experiment.	
		Metres.	Metres.	Metres.
Oxygen (from Manganese, therefore impure)...	Confined over water.	317·7	316·6	310
Azote........		339·0	338·1	310
Hydrogen........		1233·3	914·2	680 820 according to its purity.
Carbonic acid		270·7	275·3	269
Oxide of carbon (from zinc and chalk)		341·1	316·9	
Protoxide of azote (from nitrate of ammon.)....		270·6	281·4	
Deutoxide of azote (nitrous gas)......		317·4	309·8	320
Carburetted hydrogen........		337·4	317·8	
Sulphuretted hydrogen........	Confined over mercury.	305·7	318·7	
Sulphurous acid........		229·2	229·2	
Muriatic acid gas........		298·8	309·3	
Ammonia........		432·0	399·4	
Vapour of water at 54° R........		422·6	369·6	
Vapour of alcohol at 48° R........		262·7	289·1	

We give this Table, to the best of our comprehension, from a very imperfect and obscure abstract of an inaugural dissertation of M. Van Rees, (printed in 1819,) given in the *Journal de Physique*, 1821, p. 40. We have not been able to procure the original. The differences of the columns probably arise from impurities in the gases, or difficulty in estimating the exact pitch of Sounds propagated by them.

83. Peculiarity in hydrogen.

These determinations are, of course, liable to considerable errors; but the difference between the results of theory and experiment in the case of hydrogen is so great as to warrant a conclusion, otherwise not improbable, that the value of the coefficient K in that gas (at least) is materially different from what it is in others. Experiments are hardly yet sufficiently multiplied to enable us to speak with certainty on this point; but if by any means we are enabled to determine precisely the velocity of Sound, in a gas, or indeed in any medium, the ratio of the values of this coefficient in it, and in air, may be obtained by the analogy
$$K : K' :: V^2 . s : V'^2 . s';$$
which expresses that the value of K is as the square of the velocity of Sound, and the specific gravity of the medium jointly. Thus the specific gravity of pure hydrogen being to that of air as 0·0694 : 1, (Thomson, *Attempt to establish the first Principles of Chemistry*, i. 72.) and the velocity of Sound in it being to that in air as 2999·4 to 1089·4, we have

Value of K in hydrogen nearly double of its value in air.

$$K \text{ in hydrogen} : K \text{ in air} :: (2999{\cdot}4)^2 \times 0{\cdot}0694 : (1089{\cdot}4)^2 \times 1,$$
$$:: 0{\cdot}526 : 1 :: 1 : 1{\cdot}901.$$

84. Intensity of Sound differs in different media.

But not only the velocity of Sound differs in media of different chemical and mechanical natures. Its intensity, *i. e.* the impression it is capable of producing on our organs of hearing, *cæteris paribus*, also varies extremely with a variation in the density of the transmitting medium. This we have already remarked in the case of air, whether rarefied or condensed. Priestley (*Observations and Experiments*, iii. 355.) enclosed a piece of clockwork, by which a hammer could be made to strike at intervals, in a receiver filled successively with different species of gas. The distances at which the Sound ceased to be heard were measured. He thus found that in hydrogen the Sound was scarcely louder than in a vacuum, (such a one as he could produce.) In carbonic acid it was louder than in air, and somewhat louder also in oxygen. Perolle (*Mém. Acad. Toulouse*, 1781; *Mém. Acad. Turin*, 1786-1787) has described some experiments not altogether in agreement with these. The distance at which a given Sound ceased to be heard in atmospheric air being 56 feet, he found that in carbonic acid it was 48 only; while in oxygen and nitrous gas the distance was 63, and in hydrogen only 11. Chladni found the Sound of hydrogen gas in an organ-pipe remarkably feeble and difficult to distinguish, and that of oxygen stronger than that of atmospheric air, but remarked nothing particular in the case of carbonic acid. (*Acoust.* 281.)

85.

Leslie (*Camb. Phil. Trans.* i. 267.) relates some very curious experiments, by which it should appear that

Singular effect of hydrogen in enfeebling Sound.

hydrogen gas is peculiarly indisposed for the conveyance of Sound. He rarefied the air of a receiver in which a piece of clockwork was enclosed, striking a bell every half minute, 100 times; and then introduced hydrogen gas, when *no augmentation whatever* of the Sound took place. Yet more; when the air in the receiver was only half exhausted, and the deficiency filled up with hydrogen gas, not only the Sound was not increased, but was actually diminished *so as to become scarcely audible*. If this last fact be correctly stated, (which from the high character of Mr. Leslie, as an experimenter, we must not doubt,) some peculiar modification of the usual process by which Sound is propagated must have taken place. It is much to be regretted that the circumstances are not more fully stated; the *pitch* of the bell in air, in the mixed gases, and in hydrogen alone; the dimensions of the receiver; the distances at which the Sounds ceased to be heard; and whether the same effect took place when bells of different pitch were struck, and when the bell was muffled so as to produce no *musical* Sound, are all particulars of essential consequence to enable us to form a judgment of what really took place in this interesting experiment, which we venture to express a hope will be repeated and varied by its author on a scale proportioned to its importance. We shall have occasion again to refer to this subject. (See Index, *Interference* of Sonorous Vibrations and Propagation of Sound in *Mixed Media*.)

86. Effect of hydrogen on the voice when breathed.

When hydrogen is breathed (which may be done for a short time, but not altogether without inconvenience and even danger) the voice is singularly affected, being rendered extremely feeble, and at the same time raised in pitch. (Odier, *Journal de Physique*, vol. xlviii.) This is just what ought to arise from the lungs, larynx, and fauces being filled with an exceedingly rare medium; but if, as some experimenters relate, the effect subsists long after the hydrogen is expired, and the lungs completely cleared of it, this can only be ascribed to some physiological cause depending on its peculiar action on the organs of the voice. The singular Sounds produced by burning this gas in pipes of proper construction have nothing to do with the propagation of Sound *in* the gas itself.

Musical Sounds excited by the combustion of hydrogen.

87. Propagation of Sound in vapours.

The propagation of Sound in vapours offers two distinct cases in which it would at first appear that very different effects should take place. In the first, in which the vapour is subjected to a less compression than what is sufficient to reduce a portion of it to the liquid state, experiments have sufficiently proved the identity of the laws which regulate the compression and dilatation of this species of elastic fluids with those which prevail in the case of ordinary gases; and, indeed, recent researches have proved that a great number, and rendered it probable that all the latter, are in fact only vapours of certain liquids capable of sustaining a very much greater than the ordinary atmospheric pressure; or, which is the same thing, habitually maintained at a temperature far above their boiling point. In this state, then, the propagation of Sound in vapours differs in no respect from that in gases. But when the pressure sustained by the vapour is sufficient to condense a portion of it, as, for instance, in the upper part of a vessel in which water is kept boiling, and which is therefore full of steam at 212° Fahr., it would seem, at first sight, that no Sound could be propagated through such a medium; for, since the slightest additional pressure is sufficient to reduce a portion of the vapour to the liquid state, it would appear that the whole effect of an impulse suddenly communicated to any portion of the vapour, urging it towards the adjacent stratum, would be, not the compression of the whole of such portion into less dimensions, accompanied with increased elastic force, but the absolute condensation of a small portion into inelastic water, the remainder retaining precisely the same elasticity as before. Thus the necessary conditions for the propagation of the impulse are nullified, and it should seem, therefore, that no Sound could be excited in such a case.

88. Experiment proposed by Biot.

But if in vapours, as in gases, the act of compression developes a certain portion of heat, it is evident that this may be such as to prevent altogether the mechanical condensation of the compressed vapour, and maintain it in its elastic state even under the increased pressure; and therefore Sound ought on this supposition to be propagated freely. Thus it appears that we are furnished with an *experimentum crucis* for deciding on the validity of the explanation above stated of the excess of the observed above the theoretical velocity of Sound. *If* the momentary condensations and dilatations of an elastic fluid *do*, as supposed in that explanation, give out and absorb heat, Sound should be freely propagated in a *saturated vapour*, (*i. e.* a vapour in contact with liquid, or under a pressure which it can just sustain.) If not, no Sound can be transmitted by it. The experiment has been made with care by M. Biot, assisted by Messrs. Berthollet and Laplace, (*Mém. d'Arcueil*, ii. 99.) by means of a bell suspended in a large glass balloon. When completely exhausted, no Sound was heard on striking the bell; but on the admission of a little water it was feebly heard, and as the water and balloon were warmed, became stronger and stronger. When allowed to cool, the vapour condensed, and the Sound became enfeebled by the same degrees. When alcohol was used instead of water the Sound was more powerful, and still more so when ether was introduced, the vapours of these liquids at a given temperature being more dense than that of water. As in these experiments care was taken to keep the inside of the balloon constantly wet with the liquid, it is evident that the only condition requisite to be observed, that of maintaining the vapour in the interior, at its maximum of pressure, was completely fulfilled. The reader is referred to the original Memoir for an account of the details of this elegant experiment. The reasoning above stated is M. Biot's. We would remark, however, on it, that the developement of the latent heat of a vapour on its condensation into a liquid, though, no doubt, analogous to, is still in a material point different from, the developement of heat in a gas by mere compression, unaccompanied with a change of state. If the latent heat of steam at 212° (amounting to about 945°) be not conducted away, the steam cannot be condensed into water of 212°. A portion will be condensed, but its latent heat will be employed in raising the temperature of the water produced and of the remaining steam, and thus increasing its elasticity and resistance to the pressure. Thus, the propagation of Sound in saturated vapour is not incompatible with the reduction of a portion of the vapour to a liquid state at every condensation caused by the sonorous pulse, and its reconversion into vapour when the condensation goes off: nor is it to be assumed as proving any thing with respect to gases or vapours under less than their maximum pressure. The heat developed may (for any thing this experiment proves) come entirely from the liquefied

Remarks thereon.

portion, and have no existence when no portion is liquefied. We do not make this remark as detracting from the merit of M. Biot's ingenious views, in which, on the contrary, we fully coincide as to their result, but as an instance of the circumspection requisite in drawing conclusions in a theory so delicate as that of the propagation of Sound.

§ IV. *Of the Propagation of Sound through Liquids.*

89. Liquids compressible and elastic.

The experiments of Canton, and the more recent ones of Perkins, Oersted, Colladon, and Sturm, have shown that water, alcohol, ether, and, no doubt, all other liquids, are compressible and elastic, though requiring a very much greater force to produce a given diminution of bulk than air. Water, according to the experiments of Perkins, (*Phil. Trans.* 1820, p. 234.) as computed by Dr. Roget, suffers a condensation of $\frac{1}{212\cdot 36}$ by a pressure of 100 atmospheres. This result agrees sufficiently well with that of Canton, which gave a condensation of 0·000046 for every atmosphere of pressure, (*Phil. Trans.* 1764,) and has been since confirmed by Oersted's researches.

90. And therefore capable of conveying Sound.

Since water, then, and other liquids have the essential property of elastic media, on which the propagation of Sound depends, it may be presumed, *à priori*, that Sounds are capable of being conveyed by them as well as by the air; and, indeed, better, by reason of their greater density, pursuant to the same law which obtains in gases. This conclusion is abundantly confirmed by experiment. Hauksbee (*Phil. Trans.* 1726, 371.) ascertained that water would transmit a Sound excited in air. Anderon (*Phil. Trans.* 1748, p. 151.) describes a number of experiments on the hearing of fishes, from which, indeed, he concludes, that they are altogether devoid of this sense. But a very different conclusion really follows from them. Fishes enclosed in a glass jar appeared (says Anderon) utterly insensible to any Sound excited in the air without them, (if unaccompanied with motion,) but the slightest tap with the nail on the edge of the jar, although made in such a situation that the motion could not be seen by them, immediately disturbed them. This is easily explicable; and is, in fact, just what ought to happen. The intensity of Sound excited in any medium must evidently be proportioned to the energy of the original impulse, and must therefore be much greater when arising from the direct impact of a solid body on the water, or its containing vessel, than from that of the particles of the air in a sonorous wave, whose momentum is necessarily very small. As fishes have no external organs of hearing, Sounds must be conveyed to their sensorium by direct propagation, through the bones of their heads; and they are probably insensible to, or habitually careless of, those feeble impulses which are communicated from the air. But that the latter impulses do exist, and are audible by our ears, Anderon's Paper furnishes proof enough. He made three people, stripped quite naked, dive at once, and remain about two feet below the surface of the water. In this situation he spoke to them as loud as he was able. At their coming up they repeated his words, but said he spoke very low. He caused the same persons to dive about 12 feet below the surface, and discharged a gun over them, which they said they heard, but that the noise was scarce perceivable. He further caused a diver to halloo under water, which he did; and the Sound was heard, though faintly. A grenade, exploded about nine feet below the surface, gave a prodigious hollow Sound, with a most violent concussion of the earth around. Lastly, he caused a diver to descend with a bell in his hand, whose ringing he (the diver) assured him he could hear distinctly at all depths; adding, also, that he could hear the rushing of the water through a flood-gate at 20 feet distance from the place he was in.

Hearing of fishes.

Sounds excited in air heard under water.

91. Nollet's experiments.

The Abbé Nollet having descended to various depths, from 4 to 24 inches, could hear all Sounds made in the air (as a clock striking, a hunter's horn, the human voice, &c.) distinctly, but faint and attenuated. (Brocklesby, *Phil. Trans*, 1748, p. 237.)

92. Franklin's.

Franklin, having plunged his head below water, caused a person to strike two stones together beneath the surface; and at more than half a mile distance heard the blows distinctly. These instances are sufficient to show that Sound is *audibly* conveyed through water as well as through air; and, indeed, if properly excited, much better.

93. Velocity of Sound in water. Beudant's experiments

A series of experiments on the velocity of Sound in sea-water was instituted by M. Beudant, at Marseilles. Two observers, with regulated watches, were stationed in boats at a known distance. Each was accompanied by a diver. A bell was struck at stated intervals at one station; and at the instant of its being heard by the diver at the other he made a signal, and the time was noted by the observer in the boat. Of course, time was lost. The mean result of these observations gives 1500 metres = 4921 feet per second for the velocity.

94. Colladon and Sturm's experiments

A more careful and no doubt more exact determination was undertaken and executed in 1826, by M. Colladon, in the Lake of Geneva. After trying various means for the production of the Sound, as the explosion of gunpowder, blows on anvils, and bells; the latter were preferred, as giving the most instantaneous, and, at the same time, most intense Sound, the blow being struck about a yard below the surface by means of a metallic lever. The experiments were all made at night, to avoid the interference of extraneous sounds, and for the better observing of the signals made at each blow by the flash of gunpowder.

95. Method practised by them to hear Sounds in water at great distances.

To render audible to an observer out of water (in which situation only can any observations worthy of confidence be made) sounds excited at a great distance, a very ingenious method was practised by M. Colladon. He found, that although the Sound of the blow was well heard directly above the bell, yet the intensity of the Sound so propagated into the air diminished with great rapidity as the observer removed from its immediate neighbourhood, and at two or three hundred yards it could no longer be heard at all. This fact renders it probable, that the waves of Sound, like those of light, in passing from a denser into a rarer medium, undergo, at a certain acuteness of incidence, a total reflexion; (see LIGHT, Art. (184); see also Index to this Article—

Reflexion of Sound—*Echo*;) and cease to penetrate the surface, so that the Sound heard beyond that limit is merely that which diverges, *in the air*, from the point immediately above the bell. Acting on this idea, M. Colladon plunged vertically into the water a thin tin cylinder, about three yards long and eight inches in diameter, closed at the lower end, and open to the air above; thus forming an artificial surface on which the sonorous waves, impinging perpendicularly, might enter the air, and be thence propagated freely as from a new origin; just as we may look into water at any obliquity by using a hollow tube with a glass plate at the end perpendicular to the axis. This contrivance succeeded completely, and he was enabled by its aid to hear the strokes of a bell under water at a distance of 2000, 6000, and even 14,000 metres, (about 9 miles,) *viz.* across the whole breadth of the lake of Geneva, from Rolle to Thonon. A better spot could not have been found, the water being exceedingly deep, without a trace of any current, and of the most transparent purity. The signals were made by the inflammation of gunpowder, which being performed by the same blow of the hammer by which the bell was struck, all loss of time was effectually avoided. The time was reckoned by a quarter second stop-watch, from the appearance of the flash to the arrival of the Sound.

96. Result of their experiments. By the mean of 44 observations on three different days, it appeared that a distance of 13·487 metres was traversed in 9·295 seconds, the greatest deviation being less than three-tenths of a second. M. Colladon assumes 9·4 as the true interval, regarding it as probable that a minute portion of time is necessarily lost in the estimation of the interval. The mean temperature of the water, from trials made at both stations, and half way between, was found to be 8°·1 cent. (= 46°·6 Fahr.) At this temperature, then, the velocity of Sound in the water of the Lake of Geneva was 1435 metres = 4708 feet per second.

97. Comparison with theory. To compare this result with theory, we will take the data afforded by the experiments of Messrs. Colladon and Sturm on this very water; whose foreign contents, as appears by the analysis of M. Tingry, amount only to $\frac{1}{5000}$ of its weight, and which may, therefore, be regarded as pure water, (though, of course, saturated with air.) They state the compressibility, both at this and at the freezing temperature, at 0·0000495 for every atmosphere; *i. e.* that an increase of pressure of one atmosphere produces a diminution of bulk equal to $\frac{49{\cdot}5}{1{\cdot}000{\cdot}000}$ of the whole, or very nearly one two-hundred-thousandth. But as the atmospheric pressures used in their experiments were not *standard* ones, but each equal to a column of mercury 0·76 metres long, at a temperature of 10° cent., instead of 0° the compressibility by one *standard atmosphere* must be equal to

$$0{\cdot}0000495 \times \frac{\text{specific gravity of mercury at } 0^\circ \text{ cent.}}{\text{specific gravity of mercury at } 10^\circ \text{ cent.}} = 0{\cdot}0000495 \times \frac{1{\cdot}0018}{1{\cdot}0000} = 0{\cdot}000049589.$$

98. Different mode of expressing the coefficient of elasticity. To apply the general analysis by which the velocity of Sound in an elastic medium was deduced (Art. 52.) to this case, we must express the elasticity in a form somewhat different from that before employed in the case of aerial fluids. Let us then put e for the *compressibility* of any elastic medium, or, the diminution of bulk it will sustain by an additional pressure of a single atmosphere; or by immersion to the depth of 0·76 metres (= 29·927 inches) in mercury of the freezing temperature, (so that in water $e = 0{\cdot}000049589$.) Then, if we neglect the heat disengaged by compression, an infinitesimal column $d\,x$ of the medium, when compressed into a space $= d\,y$, will exert a resistance on the compressing column equal to *one atmosphere* $\times \dfrac{1 - \frac{d\,y}{d\,x}}{e}$. Let A be the area of the section of the sounding column, then will the weight of the particle $d\,x$ be represented by $\text{A}\,d\,x \times \text{D}$, where D is the density of the medium; and its elastic pressure on the section A, which separates it from the preceding particle, will be $\text{A} \times \dfrac{1 - \frac{d\,y}{d\,x}}{e} \times (h)\,\Delta$, where (h) = the *standard* height of mercury in the barometer and Δ the density of mercury *at the freezing temperature*. This, then, is the force mutually exerted between $d\,x$ and the particle immediately preceding it. Similarly the force exerted between $d\,x'$ and the particle $(d\,x)$ immediately preceding *it* is represented by $\text{A} \times \dfrac{1 - \frac{d\,y'}{d\,x'}}{e} \times (h)\,\Delta$; and the difference of these, or the whole force by which $d\,x$ is urged forwards, is therefore

$$-\,d\left\{\text{A}\,\Delta\,.\,\frac{(h)}{e}\left(1 - \frac{d\,y}{d\,x}\right)\right\} = \text{A}\,d\,x\;.\;\frac{(h)\,\Delta}{e}\;.\;\frac{d^2 y}{d\,x^2};$$

so that the accelerating force acting on $d\,x$ is

$$\frac{(h)}{e}\;.\;\frac{\Delta}{\text{D}}\;.\;\frac{d^2 y}{d\,x^2};$$

99. Resulting formula for velocity of Sound. If we take into consideration the heat developed by compression, we have only to multiply this by the coefficient K. Finally, therefore, if, as before, we represent by a the velocity of Sound, we shall have

$$a = \sqrt{\frac{2\,g\,(h)\,\Delta}{e\,\text{D}}}\,\text{K} = \sqrt{\frac{9{\cdot}8088 \times 0{\cdot}76 \times 13{\cdot}568}{0{\cdot}000049589 \times \text{D}}}\,\text{K}.$$

The specific gravity of the water of the lake at the temperature of the experiment was found to be exactly that of distilled water at its maximum density, the trifling expansion due to the excess of temperature being exactly counterbalanced by the superior density due to the saline contents, so that $D = 1$. Reducing, then, the value of a to numbers, we find

Reduced to numbers.

$$a = 1428{\cdot}2 \text{ met. } (= 4685{\cdot}6 \text{ feet}) \times \sqrt{K}.$$

100.
Heat developed by the compression of water.

As we have seen, the velocity actually observed was 1435 metres. The agreement of this with the coefficient of $\sqrt{K}$ within 7 metres (a space run over by the aqueous pulse in one 200th of a second) is so near, as to authorize the conclusion that in water, at least, the heat developed by compression, and consequent increased resistance to sudden condensation, is insensible.

101.
Curious phenomena observed in these experiments.

In the course of these experiments, M. Colladon was led to remark some very curious particulars respecting the nature, intensity, and duration of Sounds propagated by water. He observed, first, that the Sound of a bell struck under water, when heard at a distance, has no resemblance to its Sound in air. Instead of a continued tone, a short sharp sound is heard, like two knife-blades (messerklingen) struck together. The effect produced by hearing such a short dry sound, at a distance of many miles from its origin, he compares to that of seeing, for the first time, very distant objects sharply defined in a telescope. When tried at different distances, it preserved this character, varying only in intensity, so as to render it impossible to distinguish whether the sound heard arose from a violent blow at a great distance, or a gentle one near at hand. It was only when within 200 metres (about a furlong) that the musical tone of the bell was distinguishable after the blow. In air the contrary takes place, as every one knows; the shock of the first impulse of the hammer being heard only in the immediate neighbourhood of the bell, while the continued musical Sound is the only one that affects the hearing at a distance. The reason of this curious difference will be apparent when we come to speak of Musical Sounds. (See Index. *Musical Sounds. Vibrations* of Bodies in different media.)

102.
Non-divergence of the rays of Sound round obstacles in water

Another very curious and important observation of M. Colladon, is that of the effect of interposed obstacles. Sounds in air spread round obstacles with great facility, so that by a hearer situated behind a projecting wall, or the corner of a building, sounds excited beyond it are heard with little diminution of intensity. But in water this was far from being the case. When the tin cylinder, or hearing-pipe, already mentioned, was plunged into the water, at a place screened from rectilinear communication with the bell by a projecting wall running out from the shore, whose top rose above the water, M. Colladon assures us, that a very remarkable diminution of intensity in the Sound was perceived, when compared with that heard at a point very near the former, but within reach of direct communication with the bell; or, so to speak, out of the acoustic shadow of the wall. Thus the phenomena of Sound in water approximate in this respect to the rectilinear propagation of light, and may lead us to presume, that in a medium incomparably more elastic than water, the *shadow* would be still more perfect and more sharply defined. A material support is thus afforded to the undulatary doctrine of Light, against one of its earliest and strongest objections—the existence of shadows.

103.
Velocity of Sound in other liquids.

It appears, from these experiments, that the velocity of Sound in water may be correctly computed when its compressibility is known, without the necessity of having regard to the heat developed during compression. From all direct experiments hitherto made, it appears that in water, and all other liquids, the quantity of heat thus developed is either altogether insensible, or at least very minute; so that, most probably, the same thing will hold in other liquids. The Memoir of Messrs. Colladon and Sturm, then, which contains a very elaborate determination of the compressibility of a variety of liquids, will afford the means of computing the velocity of Sound in them. We, therefore, subjoin a Table of their results, and of such others as we have been able to collect.

Table of absolute compressibilities of various bodies.

Substance compressed.	Authority.	Absolute compression in millionth parts of the original volume.	Pressure by which the compression in the last column was produced.
Mercury at 0° cent.	Colladon and Sturm.	5·03	A column of mercury 0^{m}·76 high at 10° C.
Water free from air 0°	Ditto.	51·30	Ditto.
Water saturated with air at 0°	Ditto.	49·50	Ditto. (If correctly computed.)
Oil of turpentine at 0°	Ditto.	73·0	Ditto.
Nitric acid S. G. 1·403 at 0°	Ditto.	35·5	Ditto.
Concentrated sulphuric acid at 0°.	Ditto.	32·0	Ditto. (Query strength.)
Acetic acid at 0°	Ditto.	42·2	Ditto. Ditto.
Alcohol at 11°·6 cent.	Ditto.	96·2	Ditto. (Under an initial pressure of one atmosphere.)
		93·5	Ditto. (Under 8 atmosph. init. press.)
		89·0	Ditto. (Under 20 ditto.)
Sulphuric ether at 0°	Ditto.	133·3	Ditto. (Under 3 ditto.)
		118·5	Ditto. (Under 24 atmospheres.)
———— at 11°·4	Ditto.	149·3	Ditto. (Under 3 ditto.)
		141·3	Ditto. (Under 24 ditto.)
Water saturated at 20° cent. with ammonia (temp. 10°)	Ditto.	38·0	Ditto. (Under a mean pressure of about 10 atmospheres. Diminishe rapidly as the pressure increases.)
Nitric ether 0°	Ditto.	71·5	Ditto.
Acetic ether at 0°	Ditto.	79·3	Ditto. (Under 4 atmospheres.)
		71·3	Ditto. (Under 16 ditto.)
Muriatic ether at 11°2	Ditto.	85·9	Ditto. (Under 2 ditto.)
		82·25	Ditto. (Under 9 ditto.)
Linseed oil	Galy-Calazat.	46·8	One atmosphere, (doubtful.)
Olive oil	Ditto.	47·0	Ditto ditto.
Glass	Colladon and Sturm.	3·30	0·76 met. of mercury of 10° cent.
——	Galy-Calazat.	2·84	One atmosphere (?)
Copper	Ditto.	7·09	Ditto. ditto.
Lead	Ditto.	0·18	Ditto. ditto.
Water	Canton.	46·00	One atmosphere at 50° Fahr.
——	Perkins.	47·09	As computed by Dr. Roget.
——	Oersted.		

Of the Propagation of Sound in Solids and in Mixed Media.

104. Elasticity in solids, what.

Solids, if elastic, are equally well, or better, adapted for the conveyance of Sound with fluids. By elasticity in a solid is not meant a power of undergoing *great* extensions and compressions, after the manner of air, or Indian rubber, and returning readily to its former dimensions; but rather what is commonly called hardness, in contradistinction to toughness, a violent resistance to the displacement of its molecules *inter se* in all directions. Thus the hardest solids are, generally speaking, the most elastic, as glass, steel, and the hard brittle alloys of copper and tin, of which mirrors are made; and in proportion as they are so, they are adapted to the free propagation of Sound through their substance.

105. Effect of interrupted structure in solids on the propagation of Sound.

But an important condition in their constitution is homogeneity of substance; and in a substance perfectly homogeneous, we may add, too, uniformity of structure. The effect of want of homogeneity in a medium, on its power of propagating Sound, is precisely analogous to that of the same cause in obstructing the free passage of light, and (as the undulatory doctrine of light teaches) for the very same reason. The sonorous pulses, in their passage through it, are at every instant changing their medium. Now, at every change of medium, two things happen; first, a portion of the wave is reflected, (see *Reflexion* of Sound,—*Echo*, in the Index,) and the intensity of the transmitted part is thereby diminished; secondly, the direction of propagation of the transmitted part is changed, and the sonorous rays, like those of light, are turned aside from their direct course. (See *Refraction* of Sound, in the Index.) Thus the general wave is broken up into a multitude of non-coincident waves, emanating from different origins, and crossing and interfering with each other in all directions. Now, whenever this takes place, a mutual destruction of the waves, to a greater or less extent, arises, and the Sound is stifled and obstructed. Further yet:—as the parts of a non-homogeneous medium differ in elasticity, the velocities with which they are traversed by the sonorous pulses also differ; and thus, among the waves which do ultimately arrive at the same destination in the same direction, some will arrive sooner, some later. These, by the law of interference, tend mutually to destroy or neutralize each other.

106. Effect of imperfect junction of parts.

But of all causes which obstruct the propagation of Sound, one of the most effective is a want of perfect adhesion at the junctures of the parts of which such a medium consists. The effect of this may be conceived, by regarding the superficial strata of molecules of each medium when in contact, as forming together a thin film of less elasticity than either; at which, therefore, a proportionally greater reflexion of the wave will take place than if the cohesion were perfect,—just as light is much more obstructed by a tissue of cracks pervading a piece of glass, than it would be by any inequality in the composition of the glass itself.

107.
Experiment in illustration.
Greater audibility of sounds by night than by day.
Humboldt's explanation.
Another reason.

A pleasing example of the stifling and obstruction of the pulses propagated through a medium, from the effect of its non-homogeneity, may be seen by filling a tall glass (a Champagne glass, for instance) half full of that sparkling liquid. As long as its effervescence lasts, and the wine is full of air-bubbles, the glass cannot be made to *ring* by a stroke on its edge, but gives a dead, puffy, disagreeable Sound. As the effervescence subsides the tone becomes clearer, and when the liquid is perfectly tranquil the glass rings as usual; but on reexciting the bubbles by agitation, the musical tone again disappears. To understand the reason of this, we must consider what passes in the communication of vibrations through the liquid from one side of the glass to the other. The glass and contained liquid, to give a musical tone, must vibrate regularly in unison as a system; (see *Vibrations* of a System of bodies;) and it is clear, that if any considerable part of a system be unsusceptible of regular vibration, the whole must be so. This neat experiment seems to have been originally made by Chladni, (*Acoustique*, § 214,) and has been employed by Humboldt, to illustrate by it a natural phenomenon equally familiar and striking; we mean, the greater audibility of distant Sounds by night than by day. This he attributes to the uniformity of temperature in the atmosphere by night, when upward currents of air, heated by their contact with the earth under the influence of the sun's rays, are no longer continually mixing the lower with the upper strata, and disturbing the equilibrium of temperature. It is obvious that Sound, as well as light, must be obstructed, stifled, and dissipated from its one original direction, by the mixture of air of different temperatures, (and consequently elasticities;) and thus the same cause which produces that extreme transparency of the air at night, which astronomers only fully appreciate, renders it also more permeable to Sound. There is no doubt, however, that the universal and dead silence generally prevalent at night renders our auditory nerves sensible to impressions, which would otherwise escape them. The analogy between Sound and light is perfect in this as in so many other respects. In the general light of day the stars disappear. In the continual hum of noises which is always going on by day, and which reach us from all quarters, and never leave the ear time to attain complete tranquillity, those feeble Sounds which catch our attention at night make no impression. The ear, like the eye, requires long and perfect repose to attain its utmost sensibility.

108.
Sounds in mixed gases.
Obstruction of Sound by hydrogen gas mixed with air explained.

To a cause of the same kind, particularly modified, may possibly be attributable the singular effect of hydrogen gas when mixed with air, already described, Art. 85, in unfitting it for the free propagation of Sound. Chemists maintain that when gases are mixed, the molecules of each form separate and independent systems, being mutually inelastic, and each sustaining a part of the pressure proportional to its own density. They admit, however, that the molecules of one gas (A) act as obstacles, to obstruct the free motion of those of another (H;) and on this principle they explain the *slow* mixture of two gases in separate vessels communicating by a narrow aperture. Granting these postulates, let us conceive a pulse excited in a mixture of equal volumes of two gases. If the velocity of Sound in both be alike, the pulse will run on in each, although independently, yet with the same speed, and at any instant, and at any point of the medium, the contiguous molecules of both gases will be moving in the same direction and with the same velocity. They will, therefore, offer no mechanical obstruction to each other's motion, and Sound will be freely propagated. But if they differ in their specific elasticity, the case will be altered. Each being non-elastic to the other, two distinct pulses will be propagated, and will run on with different velocities; the molecules of either gas, at different points beginning, and ceasing to be agitated with the pulsation at different instants. Thus an internal motion, a change of relative position among the molecules of the gas (H) and those of the gas (A) will take place, the one set being obliged to force themselves a passage between the other; in which, of course, a portion of their motion will be diverted in all sorts of lateral directions, and will be mutually destroyed. It is evident that the greater the difference of specific elasticities, the greater will be the effect of this cause. In hydrogen the velocity of the pulse is nearly three times its velocity in atmospheric air; and, of course, it may be expected in this case to act with great efficacy. In azote and oxygen the velocities are so nearly alike, that very little obstruction can arise from its influence; so that, in so far as the phenomena of Sound are concerned, atmospheric air may be looked upon as a homogeneous medium.

109.
Duplication of Sounds occasionally observed.
Effect of carpeting, &c. in deadening Sound.

If saturated with aqueous vapour, at high temperatures, however, it is possible that the effect may become sensible, and, perhaps, to this cause may be attributed a phenomenon, mentioned by more than one experimenter on this branch of Physics, of the occasional duplication of the Sound of a gunshot heard from a great distance, a part of the Sound being transmitted quicker than the rest by aqueous vapour, or even by water in the liquid state suspended in the air. If this be the case, Sounds might be expected to be heard double in thick fogs, or in a snow-storm. But the remarkable obstruction to Sound caused by fog, and especially by snow, (see Art. 21,) would, probably, prevent any Sound from being heard far enough to permit the interval of the two pulses to be distinguishable. This latter phenomenon, we may here observe, affords another and very satisfactory illustration of the general principle explained in Art. 107. To it we may add the well-known effect of carpeting, or woollen cloth of any kind, in deadening the Sound of music in an apartment. The intermixture of air and solid fibres in the carpets through which the Sound has to pass, deadens the Echo between the ceiling and floor by which the original Sound is swelled.

110.
Phenomenon observed at Solfaterra.
Explained.

A phenomenon noticed by every traveller who visits the Solfaterra near Naples, but whose true nature has been much misconceived, is easily explicable on this principle. The Solfaterra is an amphitheatre, or extinct crater, surrounded by hills of lava, in a rapid state of decomposition by the action of acid vapours issuing from one principal and many subordinate vents and cracks. The whole soil of the level at its bottom consists of this decomposed lava, whose disintegration, however, is not so complete as to reduce it to powder; but leaves it in coherent white masses of a very loose friable structure. At a particular spot, a large stone violently thrown against the soil, is observed to produce a peculiar hollow Sound, as if some great vault were below. Accordingly it is usually cited as a proof of the existence of some vast cavity below, communicating with the ancient vent of the volcano, and perhaps with subterraneous fires; while others ascribe it to a reverberation from the surrounding hills, with which it is nearly concentric; and others to a variety of causes more or less fanciful. It seems most probable, however, that the hollow reverberation is nothing more than an assemblage of partial echoes arising from the reflexion of successive portions of the original impulse in its progress through the soil at the innumerable half-coherent surfaces composing it; were the whole soil a mass of sand, these reflexions would be so strong and frequent as to destroy the whole impulse in too short an interval to allow of a distinguishable after-sound. It is a case analogous to that of a strong light thrown into a milky medium, or smoky atmosphere; the whole medium appears to shine with a nebulous undefined light. This is to the eye, what such a hollow Sound is to the ear.

111. Essential difference in the constitution of fluids and solids.

The general principle on which the conveyance of Sound through solids depends, is precisely the same as in fluids; and the same formula may be used to express its velocity when the specific elasticity is known. There are, however, two very important particulars in which they differ; first, the molecules of fluids are capable of displacement *inter se*. Those of solids, on the other hand, are subjected to the condition of never changing their order of arrangement. Secondly, each molecule of a fluid is similarly related to those around it in all directions; in solids each molecule has distinct sides, and different relations to space and to the surrounding particles. Hence arise a multitude of modifying causes, which must necessarily affect the propagation of sonorous pulses through solids, which have no place in fluids, and modes of vibration become possible in the former, which it is difficult to conceive in the latter, whose parts have no lateral adhesion. Thus we may conceive pulses propagated in solids, like those of a cord vibrating transversely, in which the motion of each molecule is transverse, or oblique, to the direction in which the general pulse is advancing. Again, the cohesion of the molecules of crystallized bodies is different on their different sides, as their greater facility of cleavage in some directions than in others indisputably proves. They must, in consequence, have unequal elasticities in different directions; and thus the velocity of the pulse propagated through a crystallized solid will depend on its direction with respect to the axes of crystallization. Among uncrystallized solids, too, there are many, such as wood, whalebone, &c. which have a fibrous structure, in virtue of which, it is evident, they are very differently adapted to convey an impulse longitudinally and transversely.

Propagation of oblique or transverse undulations.

Propagation of pulses in crystallized media.

112. Wood an excellent conductor of Sound.

Interruptions of crystalline structure, then, ought to produce an effect on the conveyance of Sound analogous to that of the mixture of extraneous matter in a medium. The conducting power of wood along the grain is certainly very surprising. A simple experiment will show it. Let any one apply his ear close to one end of the longest stick of sound timber, and let an assistant at the other end scratch with the point of a pin, or tap so lightly with its head as to be inaudible to himself. Every scratch or tap will be distinctly, nay loudly, heard at the other end, as if close to the head. In general, however, all solids tolerably compact conduct Sound well, and transmit it rapidly.

113. Conduction of Sound along a wire.

Chladni relates an experiment made by Messrs. Herhold and Rafn, in Denmark, where a metallic wire 600 feet long was stretched horizontally. At one end a plate of sonorous metal was suspended, and slightly struck; an auditor placed at the other, and holding the wire in his teeth, heard at every blow two distinct sounds; the first transmitted almost instantaneously by the metal, the other arriving later through the air. Messrs. Hassenfratz and Gay Lussac made a similar experiment in the quarries at Paris; a blow of a hammer against the rock produced two Sounds, which separated in their progress; that propagated through the stone arriving almost instantly, while the Sound conveyed by the air lagged behind. The same thing has been observed in the blasting of rocks in the deep mines of Cornwall. These experiments were, however, made at intervals too short to give any numerical estimate of the velocity of transmission of Sound in the iron or stone. The only direct experiments we have on this subject are those of M. Biot himself, who, assisted by Messrs. Bouvard, Malus, and Martin, ascertained the interval required for the Sound of a blow on the cast-iron conduit pipe already spoken of, Art. 24, to traverse measured lengths of it. The pipe consisted of joints of cast iron, each $2^{\cdot\text{met}}515 = 8\cdot2514$ feet long, and connected by flanches with collars of lead covered with tarred cloth interposed, and strongly screwed home; each collar measured $0^{\cdot\text{met}}14256 = 0^{\cdot\text{f}}\cdot46773$. A blow being struck at one end, and heard at the other, the interval between the arrival of the Sound through the air and through the iron was noted. The length being known, the time required for the transmission of the aerial Sound became known with great precision, and thence the time of transmission through the iron became known also. The following is a statement of the results:

Through rocks.

Through cast iron. Biot's experiments.

Observers' names.	Number of iron joints.	Number of leaden collars.	Total length when connected in metres.	Observed interval of the sounds in seconds.	Number of observations.	Computed time of transmission in air. Seconds.	Deduced time of transmission through the compound solid.
Biot, Bouvard ...	78	77	197·27	0·542	53	0·579	0·037
Bouvard, Malus..	156	155	394·55	0·810	64	1·158	0·348
Biot, Martin	376	375	951·25	2·500	200	2·790	0·290
Ditto do.	ditto.	ditto.	ditto.	Time directly observed by a different method.			0·260

114. Actual observed velocity of Sound in cast iron.

The last result was obtained as follows. Each observer holding in one hand a chronometer and in the other a hammer, (the chronometers being carefully compared,) the one (M) at the precise beats of $0^{s\cdot}$ and $30^{s\cdot}$ struck on the pipe, and the other noted the moment of arrival of that Sound *only* which was propagated through the solid, (*i. e.* the first.) At every $15^{s\cdot}$ and $45^{s\cdot}$, and also precisely on the beat of his chronometer, the observer (B) struck the pipe, and (M) noted in the same manner the moment of arrival of the metallic Sound by *his* watch. From such reciprocal observations, a very little consideration will show that the exact time required for the Sound's propagation through the solid may be obtained, independent of any observation of the aerial Sound, as well as of the rates of the watches. The agreement of the results obtained by the two methods sufficiently proves that the result of Messrs. Bouvard and Malus, in the above Table, is too large; rejecting this for that reason, and the first on account of the shortness of the pipe, we have, as a mean result, $0^{\cdot s \cdot}275$ for the time required to traverse 951·25 metres, which gives a velocity of $3459^{\cdot met \cdot}1 = 11090$ feet per second for the velocity of Sound in cast iron at the temperature of the experiment, (11° cent. = 51°·8 Fahr.) and neglecting the very small retardation due to the collars, whose united thickness was $5^{\cdot met}61 = 18^{\cdot f \cdot}41$ only. This is about 10½ times its velocity in air. Chladni assigns 3597 metres for the velocity of Sound in brass. Laplace, calculating on an experiment of Borda, on the compressibility of brass, makes it 3560·4. According to Chladni, the following are the velocities of Sound in different solids, that in air being taken for unity: tin = 7½, silver = 9, copper = 12, iron = 17, glass = 17, baked clay (porcelain ?) 10. . . . 12, woods of various species = 11. . . . 17. The error in the case of iron throws a doubt on all the rest; unless, perhaps, steel be meant. (*Acoust.* § 219.)

Its velocity in brass.

115. From this determination we may estimate the time it requires to transmit force, whether by pulling, pushing, or by a blow, to any distance, by means of iron bars or chains. For every 11090 feet of distance the pull, push, or blow, will reach its point of action one second after the moment of its first emanation from the first mover. In all moderate distances, then, the interval is utterly insensible. But were the sun and the earth connected by an iron bar, no less than 1074 days, or nearly three years, must elapse before a force applied at the sun could reach the earth. The force actually exerted by their mutual gravity may be proved to require no appreciable time for its transmission. How wonderful is this connection!

Time required to transmit force by iron rods, levers, &c.

§ VI. *Of the Divergence and Decay of Sound.*

116. Hitherto we have taken no account of the lateral divergence of Sound, which we have supposed confined by a pipe; but it is evident that condensation taking place in any section of such a channel will urge the contained air laterally against the side of the pipe, as well as forward along its axis; and, consequently, if the pipe were cut off at any point, the Sound would diverge from that point into the surrounding air. Accordingly, when any one speaks through a long straight tube the voice is heard laterally, as if proceeding from the mouth of a speaker at the orifice.

Divergence of Sound from the end of a pipe.

117. In general, a Sound excited in, or impulse communicated to, any portion of the air or other elastic medium, spreads, more or less perfectly, in all directions in space. We say more or less perfectly; for though there are Sounds, as the blow of a hammer, the explosion of gunpowder, &c. which spread equally in all directions, yet there are others which are far from being in that predicament. For instance, a common tuning-fork (a piece of steel in the shape represented in fig. 6) being struck sharply, when held by the handle (A) against a substance, is set in vibration, the two branches of the fork alternately approaching to and receding from each other. Each of them, consequently, sets the air in vibration, and a musical tone is produced. But this Sound is very unequally audible in different directions. If the axis of the fork, or the line to which it is symmetrical, be held upright about a foot from the ear, and it be turned round this axis while vibrating, at every quarter revolution the Sound will become so faint as scarcely to be heard, while in the intermediate axes of rotation it is heard clear and strong. The audible situations lie in lines perpendicular and parallel to the flat faces of the fork, the inaudible at 45° inclined to them. This elegant experiment, due originally to Dr. Young, has recently been called into notice by Weber. (Wellenlehre, § 271.)

Unequal divergence of certain Sounds. Fig. 6.

Exemplified in Sound of a tuning-fork.

118. The non-uniformity of the divergent pulses which constitute certain Sounds is easily demonstrated by considering what happens when a small disc is moved to and fro in a line perpendicular to its surface. The aerial molecules in front of the disc are necessarily in an opposite state of motion from those similarly situated behind it. Hence, if we conceive a wave propagated spherically all around it, the vertices of the two hemispheres in front and behind are in opposite motions with respect to the centre. But with regard to that wave of the sphere where the vibrating plate prolonged cuts it, there is evidently no reason why *its* molecules should approach to or recede from the centre, or, rather, there is as much reason for one as for the other. They will therefore either remain at rest, or move tangentially; so that the motion of the whole sounding surface, or wave, will, in this case, be rather as in fig. 7 than in fig. 8; and a corresponding difference, both in the intensity and character of the Sound heard in different directions, may be fairly expected.

A priori considerations.

Fig. 7. Fig. 8.

119. 120. The mathematical theory of such pulses as these is of the utmost complication and difficulty, depending on the integration of partial differential equations with four independent variables, *viz.* the time and the three coordinates of the moving molecules. It is therefore of much too high a nature to have any place in an Essay like the present. We shall merely content ourselves with stating the following as general results in which mathematicians are agreed.

Velocity of Sound in free air.

121. 1st. The velocity of propagation of a sonorous pulse is the same, whether we regard it as propagated in one, two, or three dimensions, *i. e.* in a pipe, a lamina, or a mass of air.

Law of the decay of Sound.

2nd. Sounds propagated in a free mass of air diminish in intensity as they advance further from the sonorous centre, and their energy is in the inverse duplicate ratio of this distance, *cæteris paribus.*

122. We shall not attempt a proof of these propositions in the general cases, but content ourselves with illustrating them in one particular but important case, *viz.* when the initial impulse is confined to a very small space, and consists in any small radiant motion of all the particles of a spherical surface in all directions equally from the centre.

Case of a spherical undulation alike on all sides.

123. Since the initial wave is spherical, and similar in all its parts, it will evidently retain this property as it dilates

by the progress of the impulse. If, then, it be conceived to be divided into its infinitesimal elements by a system of pyramidally disposed plane surfaces, having the common vertex in the centre of the sphere, each of these elements will form the base of one of the pyramids, and its molecules will advance and recede along its axis, as the pulse traverses them, without any change of their relative positions, *inter se;* so that the whole wave may be regarded as broken up into partial waves, each advancing as if confined within a pyramidal pipe, independently of all the rest.

124. Velocity of a pulse in any pyramidal pipe.

Now in any one of these imaginary pipes the pulse will be propagated from layer to layer of the included particles with the same velocity as if the pipe were cylindrical, for the divergence of the sides of the pipe can only cause a lateral extension, and thence a diminished thickness, of the stratum, and will, therefore, alter the *velocity* of each of its molecules and the extent and law of its motion from what it would be in a cylindrical pipe. But if we consider a row of particles situated in the axis of the pyramid, the propagation of a pulse along them depends, as we have seen, neither on the velocity nor extent or law of excursion of the individual molecules, but only on their *intrinsic* elasticity. The latter, however, is not altered by the shifting of the whole vibrating fibre into a wider or narrower part of the pipe, since, from *this* cause,(its excursions from its original place being supposed infinitely small,) the whole dilates or contracts together, as if by an external compressing or rarefying force. Now we have seen that a variation in the *general* density of the medium in which a pulse is propagated from external pressure makes no change in its velocity. It follows, then, that the pulse will be propagated with equal velocity along the line of molecules in question, whether the pipe be cylindrical or pyramidal, or, indeed, of any shape; and as it runs equally fast in each of the imaginary pyramids into which the sphere is divided, the wave, of which it is an element, will dilate itself spherically with the uniform velocity of Sound in a straight tube. See also Euler, *Comm. Petrop.* 1771, cap. iv. &c., where the general equations for the motions of air in tubes of any figure are deduced, and the above proposition proved therefrom, in the case of hyperbolic tubes (p. 391) and conical or pyramidal ones (p. 418.)

125. Application of the law of *vis viva.*

Let us now conceive a spherical wave by any means excited, such that the whole interval, reckoned along its radius, within which the motion to and fro of the molecules is comprised, shall be equal to $2\,a$. This, then, will be the breadth of the wave, and as all its parts dilate equally fast, this will continue to be its breadth throughout its whole progress. Its surface increases in the ratio of the square of the radius, and, therefore, calling r this radius, $2\,a\,r^2$ will represent the quantity of matter in motion at the moment the Sound has reached the distance r from its origin. Now, as all the air within and beyond the wave is quiescent, the whole impulse, or *vis viva*, originally communicated to the sphere first set in motion, is successively transferred to all the rest without loss or increase, (by the general law of the conservation of the *vis viva.* See MECHANICS.) And since it is distributed equally over the whole spherical surface, any portion of it, of given magnitude, (that of the aperture of the ear, for instance,) will receive a part of the whole, proportional to $\frac{1}{2\,a\,r^2}$, or to $\frac{1}{r^2}$. Thus the whole shock or impulse given to the ear, while the wave passes over it, is as the inverse square of the distance from its origin, and the absolute velocity of each molecule in any determinate phase of its motion inversely as the distance itself.

126. Effect on the ear estimated by the *vis viva.*

In the theory of Sound, as in that of Light, the intensity of the impression made on our organs is estimated by the shock, impetus, or *vis viva,* of the impinging molecules, which is as the square of their velocity; and not by their inertia, which is as the velocity simply. Were the latter the case, there could be no such thing as Sound or Light, since the negative inertia of the receding molecules would exactly equal and destroy their positive effect in their advance. (*Vide* LIGHT, Art. 578.) We conclude, then, that the intensity of Sound decays, in receding from its origin, as the square of the distance increases. It is exceedingly difficult to subject this law to satisfactory experimental tests, and we know of no attempt that has yet been made for the purpose.

Law of decay of Sound.

§ VII. *Of the Reflexion and Refraction of Sound, and of Echos.*

127. Reflexion of Sound at the confines of two media.

As there is no body in nature absolutely hard and inelastic, whenever the particles of a vibrating medium impinge on the solid or fluid matter which contains or limits it, they will agitate those of the latter with motions similar to their own, but modified by their greater or less density and mobility. A pulse, then, will be propagated into the solid or fluid according to its own laws, but this will not take place without the propagation back again of a pulse in the original medium, which may be regarded as the reflexion or echo of the first. To understand how this happens, let us consider what takes place when a motion is first impressed on any small stratum, whose thickness is $2\,a$ (as in Art. 63) of a sounding column, and let its law be as there expressed, *i. e.* that the velocity of any one of its particles at the distance x from its middle shall be, at the first instant, represented by $\phi(x)$, and the linear extent of the same molecule, compared with its original length, or e, shall equal $\psi(x)$ where $\varphi(x) = o$, and $\psi(x) = 1$ from $x = -\infty$ to $x = -a$, and from $x = +a$ to $x = +\infty$; while from $x = -a$ to $x = +a$ they may have any arbitrary values.

128. Condition of the single propagation of a pulse.

Since t is always positive, if we take $x > +a$ we have, of necessity, $x + a\,t > +a$, and, therefore, $\phi(x + a\,t) = o$, and $\psi(x + a\,t) = 1$, so that the values of v and e in equations (i) (j) become

$$\left.\begin{aligned} v &= \frac{1}{2}\left\{a + \phi(x - a\,t) - \psi(x - a\,t)\right\} \\ a\,e &= \frac{1}{2}\left\{a - \phi(x - a\,t) + \psi(x - a\,t)\right\} \end{aligned}\right\};$$

which gives $$ae = a - v, \text{ or } 1 - e = \frac{v}{a}.$$

Again, on the negative side of the x we take $x < -a$, we have, of necessity, $x - at < -a$, and, therefore, $\phi(x - at) = 0$; $\psi(x - at) = 1$, and, consequently,

$$\left.\begin{aligned} v &= \frac{1}{2}\left\{-a + \phi(x + at) + \psi(x + at)\right\} \\ ae &= \frac{1}{2}\left\{a + \phi(x + at) + \psi(x + at)\right\} \end{aligned}\right\};$$

and, therefore, in this case, $$1 - e = -\frac{v}{a}.$$

Now $1 - e = 1 - \frac{dy}{dx} = \frac{dx - dy}{dx}$ expresses the condensation the molecule dx has undergone in its disturbed state. Hence we see, that in each of the two waves into which the primary impulse separates itself, one running towards the positive, the other towards the negative side of the x, there obtains this condition, *viz.* that *the condensations of the aerial molecules are proportional to their actual velocities*, the fluid being *condensed* wherever the molecules are moving *from* the origin of the first impulse, and dilated when returning to it.

129. If this condition obtain, a pulse will not divide itself.

This remarkable relation, which does not of necessity hold good within the limits of the first disturbance, establishes a distinction equally marked between the initial impulse and the waves freely propagated from it. The former is subject to no law, the latter must obey this condition. Any impulse, then, in which this condition is not satisfied, will immediately divide itself into two pulses running opposite ways, in each of which the condition in question holds, but so long as this condition obtains, no subdivision of the pulse will take place. This is easily shown, for if we suppose an initial impulse communicated to any portion ($2a$) of the fluid in which this relation is purposely maintained, such supposition is equivalent to making

$$a(1 - \psi(x)) = \phi(x),$$

which, substituted in (i) and (j), give, for all values of x and t,

$$\begin{aligned} v &= a - a\psi(x - at) \\ ae &= \psi(x - at), \end{aligned}$$

in which, whenever x is negative and $< -a$, we have $v = 0$ and $1 - e = 0$; thus indicating that the molecules on the negative side of such a primitive disturbance as supposed will remain constantly at rest, in other words, that the pulse will only be propagated on the positive side.

130. If disturbed the pulse will divide and a part run back.

Whenever, then, in the progress of a pulse through a medium, it receives, by extraneous causes, any modification which disturbs the condition $1 - e = \frac{v}{a}$, it will undergo subdivision, and a portion will run backward, or be reflected. Similarly this portion may be again subdivided and undergo partial reflexion, and so on *ad infinitum*, giving rise to a continual series of repetitions or Echos of the original Sound.

131. General equations of propagation of Sound along pipes filled with different media.

Let us now examine more closely what passes at the junction of two media when the pulse arrives there; and, first, in the equations (i) and (j) let us write, instead of $\phi(x)$ and $\psi(x)$, which are arbitrary, the combinations, equally arbitrary,

$$\begin{aligned} \phi(x) &= F(x) + f(x) \\ \psi(x) &= 1 + \frac{F(x) - f(x)}{a}, \end{aligned}$$

when it is to be observed that F and f are not the same with the F and f of Art. 57, which we shall have no more occasion to refer to. If, then, we put $s = 1 - e$, so that s shall represent the infinitely small condensation undergone by the molecule dx in its troubled state, those equations will become

$$\left.\begin{aligned} v &= f(x - at) + F(x + at) \\ as &= f(x - at) - F(x + at) \end{aligned}\right\}. \qquad \text{(A)}$$

These represent the state of the molecules of the first medium. Similarly, the state of those in the second will, of necessity, be represented by another system similar in form,

$$\left.\begin{aligned} v' &= f'(x - a't) + F'(x + a't) \\ a's' &= f'(x - a't) - F'(x + a't) \end{aligned}\right\}; \qquad \text{(B)}$$

where a' represents the velocity of Sound in the second medium, but the functions f' and F′ (which are not here intended to represent the *derived* functions or differential coefficients of f and F, but others quite distinct) are here no longer arbitrary, because the motion of the particles of the second medium must evidently depend on that of the first, and on their relative elasticities, densities, &c. Let us see, then, what conditions the nature of the case, and their mutual action at their point of junction, will enable us to assign for deducing the forms of these functions from those of f and F, supposed to remain arbitrary.

Now, first, the condition of continuity of the two media requires that the strata in contact should always have a common motion, or that for the value $x = l$, corresponding to the place of junction, we should have $v = v'$, which gives

132. Condition of continuity.

$$f(l - at) + F(l + at) = f'(l - a't) + F'(l + a't); \qquad (C).$$

133. Must have a common elasticity at their junction.

Again, they must not only have a common motion, but a common elasticity, at this point. Now, if we call E the natural elasticity of the first medium and E′ that of the second, the elasticities in the disturbed state will be expressed by $E(1 + \beta s)$ and $E'(1 + \beta' s')$, where β and β' are constant coefficients depending on the nature of the media and the heat developed in them by compression, and which would each be unity were no heat so developed. Hence we must have $E(1 + \beta s) = E'(1 + \beta s')$, and since in the state of equilibrium $E = E'$, we must also have $\beta s = \beta' s'$, that is

$$\frac{\beta}{a}\left\{f(l - at) - F(l + at)\right\} = \frac{\beta'}{a'}\left\{f'(l - a't) - F'(l + a't)\right\};$$

or, putting

$$c = \frac{\beta'}{\beta} \times \frac{a}{a'}$$

$$f(l - at) - F(l + at) = c\,\{f'(l - a't) - F'(l + a't)\}; \qquad (D).$$

134. Suppose the whole extent of both media to be initially at rest (and, therefore, $v = v' = s = s' = 0$), for every value of x, but those comprised within the region of the primitive disturbance ($x = \pm \alpha$), supposed very minute and situated at the origin of the x, we shall have then

$$f'(x) = 0 \text{ and } F'(x) = 0 \text{ from } x = l \text{ to } x = \infty,$$

and since t is necessarily positive, and also a', therefore

$$f'(l + a't) = 0 \text{ and } F'(l + a't) = 0.$$

The equations C and D then become

$$f(l - at) + F(l + at) = f'(l - a't)$$
$$f(l - at) - F(l + at) = cf'(l - a't);$$

and, consequently,

$$f(l - at) - F(l + at) = c\,\{f(l - at) + F(l + at)\}. \qquad (E).$$

135. Division of the pulse on encountering an obstacle.

Now this equation is equivalent to $as = cv$; x being supposed $= l$, (equation A.) Consequently, whatever be the motion of the first medium, the existence of a second, in contact with it, establishes at their point of junction a relation between the velocity v and the condensation s of its terminal stratum, which is incompatible with the condition $as = v$, (unless in the very peculiar case where $c = 1$,) which we have shown to be essential to the total propagation of the pulse forward. It will, therefore, divide itself conformably to what was said in Art. 129, and a portion will run back in the first medium and cause an Echo.

136. But is propagated singly beyond it.

In the second medium, on the other hand, we have constantly $x > l$, and, therefore, $x + a't > l$, so that $F'(x + a't) = 0$, and, therefore, the equations (B) give

$$v' = a's' = f'(x - a't); \qquad (F.)$$

The condition of the single propagation of the pulse onward in this medium $v' = a's'$ being therefore satisfied, no further subdivision of the pulse will take place, and each particle of the second medium will be agitated once and no more. The reader who would pursue this discussion (a very delicate one) further, is referred to M. Poisson's Memoir, *Sur le Mouvement des Fluides Elastiques dans des Tuyaux Cylindriques*, *Mém. Acad. Par.* 1818, 1819. See also a very curious Paper by Euler, *Sur la Propagation du Son et sur la Formation de l'Echo*, *Mém. Acad. Berlin*, 1765, p. 355; where he shows how an echo may be formed at the open mouth of a tube, by the mere conditions to be satisfied by the arbitrary functions, and without any *reflexion* properly so called. It is enough that the condition $as = v$ should be disturbed (as it will by the sudden breaking off of the pipe) to cause an echo. See also Weber, *Wellenlehre*, § 276, who shows how this disturbance takes place, owing to the greater freedom of motion suddenly attained by the particles when the pulse reaches the free air.

137. Oblique refraction of Sound.

If we suppose a plane wave of indefinite extent to fall obliquely on the surface of a second elastic medium, each particle of this surface may be regarded as being put in agitation by it and becoming a separate and independent centre, from which spherical waves originate and are thence propagated in either medium with the velocity peculiar to it. Now, if we investigate the surfaces which in either medium are common tangents to all these spheres, and which, therefore, will be the form of the general or resulting waves in each, we shall find them to be planes; that in the medium of incidence being inclined to the surface at an angle equal to that made with it by the incident wave, and that in the other medium at an angle whose cosine is to the cosine of that made with it by the incident wave as the velocity of propagation of the wave in the first medium to that in the second. For the demonstration of these propositions we shall refer to our article on LIGHT, Art. 586. Thus the reflexion and refraction of Sound at oblique surfaces obeys the same geometrical laws with those of Light. The observation of Messrs. Colladon and Sturm, above cited, Art. 95, shows that this analogy extends to the case of oblique internal reflexion at the surface of a less elastic medium, which, at a certain incidence, becomes total.

Internal total refraction.

PART II.

OF MUSICAL SOUNDS.

§ I. *Of the Nature and Production of Musical Sounds.*

Part II.

138. Perception of Sounds in general.

EVERY impulse mechanically communicated to the air, or other sonorous medium, is propagated onward by its elasticity as a wave or pulse; but, in order that it shall affect the ear as an audible sound, a certain force and suddenness is necessary. Thus the slow waving of the hand through the air is noiseless, but the sudden displacement and collapse of a portion of that medium by the lash of a whip produces the effect of an explosion. It is evident that the impression conveyed to the ear will depend entirely on the nature and law of the original impulse, which being completely arbitrary, both in duration, violence, and character, will account for all the variety we observe in the continuance, loudness, and quality of Sounds. The auditory nerves, by a delicacy of mechanism, of which we can form no conception, appear capable of analyzing every pulsation of the air, and appreciating immediately the law of motion of the particles in contact with the ear. Hence all the qualities we distinguish in Sounds—grave or acute, smooth, harsh, mellow, and all the nameless and fleeting peculiarities which constitute the differences between the tones of different musical instruments—bells, flutes, cords, &c., and between the voices of different individuals or different animals.

139. *Noise*, as distinguished from musical Sound.

Every irregular impulse communicated to the air produces what we call a *noise*, in contradistinction to a musical Sound. If the impulse be short and single we hear a crack, bounce, or explosion; yet it is worthy of remark, as a proof the extreme sensibility of the ear, that the most short and sudden noise has its peculiar character. The crack of a whip, the blow of a hammer on a stone, and the report of a pistol, are perfectly distinguishable from each other. If the impulse be of sensible duration and very irregular we hear a crash, if long and interrupted, a rattle or a rumble, according as its parts are less or more continuous, and so for other varieties of noise.

140. Continuous Sound.

The ear, like the eye, retains for a moment of time, after the impulse on it has ceased, a perception of excitement. In consequence, if a sudden and short impulse be repeated beyond a certain degree of quickness, the ear loses the intervals of silence and the Sound appears continuous. The frequency of repetition necessary for the production of a continued Sound from single impulses is, probably, not less than sixteen times in a second, though the limit would appear to differ in different ears.

141. Periodical impulses produce musical Sounds. Pitch.

If a succession of impulses occur, at exactly equal intervals of time, and if all the impulses be exactly similar in duration, intensity, and law, the Sound produced is perfectly uniform and sustained, and has that peculiar and pleasing character to which we apply the term musical. In musical Sounds there are three principal points of distinction, the pitch, the intensity, and the quality. Of these, the intensity depends on the violence of the impulses, the quality on their greater or less abruptness, or, generally, on the law which regulates the excursions of the molecules of air originally set in motion. The pitch is determined solely by the frequency of repetition of the impulse, so that all Sounds, whatever be their loudness or quality, in which the elementary impulses occur with the same frequency, are at once pronounced by the ear to have *the same pitch*, or to *be in unison*. It is the pitch only of musical Sounds whose theory is susceptible of exact reasoning, and on this the whole doctrine of harmonics is founded. Of their qualities and the molecular agitations on which they depend, we know too little to subject them to any distinct theoretical discussion.

142. Means of producing periodical impulses.

The means by which a series of equidistant impulses, or, to speak more generally, by which an initial impulse of a periodical nature (*i. e.* capable of being represented by a periodical function) can be produced mechanically, are extremely various. Thus, if a toothed wheel be turned round with uniform velocity, and a steel spring be made to bear against its circumference with a constant pressure, each tooth, as it passes, will receive an equal blow from the spring, and the number of such blows per second will be known, if the velocity of rotation and number of teeth in the wheel be known.

143. The Sirene.

The late Professor Robison devised an instrument in which a current of air passing through a pipe was alternately intercepted and permitted to pass by the opening and shutting of a valve or stopcock. When this was performed with sufficient frequency (which could only be done, we presume, by giving a rapid rotatory motion to the stopcock by wheelwork) a musical tone was produced, whose pitch became more acute as the alternations became more frequent. This is precisely the principle of the Sirene of Baron Cagniard de la Tour. In this elegant instrument the wind of a bellows is emitted through a small aperture, before which revolves a circular disc, pierced with a certain number of holes arranged in a circle concentric with the axis of rotation, exactly equidistant from each other, and of the same size, &c. The orifice, through which the air passes, is so situated, that each of these holes, during the rotation of the disc, shall pass over it and let through the air, but the disc is made to revolve so near the orifice, that in the intervals between the holes it shall act as a cover and intercept the air. If the holes be pierced obliquely, the action of the current of air alone will set the disc in motion: if perpendicular to the surface, the disc must be moved by wheelwork, by means of which its velocity of rotation is easily regulated and the number of impulses may be exactly counted. The Sound produced is clear and sweet, like the human voice. If, instead of a single aperture for transmitting the air, there be several, so disposed in a circle of equal dimension with that in which the holes of the disc are situated, that each shall be opposite one corresponding hole when at rest, these will all form Sounds of one *pitch*, and being heard together will reinforce each other. The Sirene sounds equally when plunged in water, and fed by a current of that fluid, as in air; thus proving that it is the number of impulses alone, and nothing depending on the nature of the medium in which the Sound is excited, that influences our appreciation of its pitch.

144. Echos from a series of palisades.

In general, whatever cause produces a succession of equidistant impulses on the ear, causes the sensation of a musical Sound, whether such periodicity be a consequence of periodical motions in the origin of the Sound, or of the mode in which a single impulse is multiplied in its conveyance to the ear. For example, a series of broad palisades set edgeways in a line directed from the ear, and equidistant from each other, will reflect the Sound of a blow struck at the end of the line nearest the auditor, producing a succession of echos, which (by reason of the equidistance of the palisades) will reach his ear at equal intervals of time, $\left(= 2 \times \frac{\text{distance of palisades}}{\text{velocity of Sound}}\right)$, and will therefore produce the effect of a number of single impulses originating in one point. Thus a musical note will be heard whose pitch corresponds to a number of vibrations per second, equal to the quotient of the velocity of Sound by twice the distance of the palisades.

145. Singing of a bullet.

A similar account may be given of the singing Sound of a bullet, or other missile, traversing the air with great rapidity. The bullet being in a state of rapid rotation, and not exactly alike in all its parts, presents, periodically, at equal intervals of time and space, some protuberance or roughness first to one side, then to the other. Thus an interruption to the uniformity of its mode of cutting through the air is periodically produced, and reaches the ear in longer or shorter equal intervals of time, according as the rectilinear velocity of the bullet bears a greater or less ratio to the velocity of its rotation about its axis.

146. Echos in a chamber. Vibrations of elastic bodies.

The echos in a narrow passage, or apartment of regular figure, being regularly repeated at equal very small intervals, always impress the ear with a musical note; and this is, no doubt, one of the means which blind persons have of judging of the size and shape of any room they happen to be in. But the most ordinary ways in which musical Sounds are excited and maintained consist in setting in *vibration* elastic bodies, whether flexible, as stretched strings, or membranes; or rigid, as steel springs, bells, glasses, &c. or columns of air of determinate length enclosed in pipes. All such vibrations consist in a regular alternate motion to and fro of the particles of the vibrating body, and are performed in strictly equal portions of time. They are, therefore, adapted to produce musical sounds by communicating that regularly periodic initial impulse to the aerial molecules in contact with them which such sounds require. We shall, therefore, proceed to consider more particularly the principal of these modes of production; but especially, at present, the first and last, being the most simple cases.

§ II. *Of the Vibrations of Musical Strings or Cords.*

147. Vibration of a stretched cord.

If a string, or wire, be stretched between two fixed pins, or supports, and then struck, or drawn a little out of its straight line, and suddenly let go, it will vibrate to and fro, till its own rigidity, and the resistance of the air, reduce it to rest; but if a *bow* (which is an instrument composed of a bundle of fibres of horse hair, loosely stretched, and rendered adhesive by rubbing with rosin) be drawn across it, the vibrations are continually renewed, and may be maintained for any length of time, and a musical Sound is heard corresponding to the rapidity of the vibration.

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The mathematical theory of the vibrations of a stretched cord is remarkable, in an historical point of view, as having given rise to the first general solution of an equation of partial differences; and led geometers to the consideration of the nature and management of the arbitrary functions which enter into the integrals of these equations. Such functions, as we have seen, enter into the general expressions for the motion of the air in Sound; and such, as we shall presently show, into that of the molecules of a vibrating cord; and a long and lively discussion, on the degree of generality which ought to be attributed to them, soon arose between Euler, D'Alembert, D. Bernouilli, and Lagrange. It is not, however, our intention in this Article to enter into any points of historical detail, and we shall content ourselves with a reference to the principal Memoirs, &c. on the subject, which the reader may consult for himself; while we proceed to give such a view of the subject as is consistent with the present state of knowledge on this delicate point, and sufficient for the purpose we have in hand. See

References.

Taylor, *De Motu Nervi Tensi*, *Phil. Trans.* 1713-26; D'Alembert, *Mém. Acad. Berl.* 1747; Ditto, 1753; Ditto *Opuscules*, tom. i.; Euler, *Mém. Acad. Berl.* 1753; Daniel Bernouilli, Ditto; Lagrange, *Miscellanea Taurin.* vol. i. See also Sauveur, *Mém. Acad.* for 1713, p. 324: J. Bernouilli, on Vibrating Cords, *Petrop. Comm.* iii. 13; Daniel Bernouilli, Ditto, p. 62; Ditto, on Vibrations of Unequal Cords, *Acad. Berl.* 1765, p. 81; Ditto, on Vibrations of Compound Cords, *N. Comm. Petropp.* xvi. 257; Euler, *Acad. Berl.* 1748, p. 69; Ditto, Ditto, 1765, p. 307, 335; Ditto, on Unequal Vibrating Cords, *N. Comm. Petropp.* xvii. 381; Ditto, 1780, iv. ii. 99.

149. Solution of the problem of the motions of a stretched cord. Fig. 9.

Let M N (fig. 9) be a cord maintained by any means in a constant state of equal tension throughout, and disturbed by any external cause from its rectilinear position, and then left to take its own form and motion in consequence of its tension; its gravity, however, being neglected. Let M A B C D N be the figure of the cord after the lapse of any time t from the initial disturbance; respecting which we will only suppose that the distance of all its points from the axis V T (the undisturbed rectilinear position of the cord) is extremely small; so that in this theory, as in that of the sonorous vibrations of the air, we concern ourselves only with such excursions of the vibrating molecule as may be considered infinitely minute. Let A B C D be points of the cord infinitely near each other; and erecting the ordinates A P, B Q, C R, D S, and drawing A a, B b, C c, D d, parallel to V T put $VP = x$, $VQ = x'$, $VR = x''$, &c. and $AP = y$, $BQ = y'$, $CR = y''$, &c. Let the tension of the cord at rest be represented by c, which (since the cord is infinitely little disturbed from its position of repose) will also be its tension in its disturbed state; and will in this, as in the former state, be uniform over its whole length, the curvature being evanescent. The point B of the cord then will be solicited towards the axis by the tension c applied at B, and acting in the direction B A, and whose resolved value is, therefore,

$$c \,.\, \frac{B\,a}{B\,A} = c \,.\, \frac{d\,y}{\sqrt{d\,x^2 + d\,y^2}} = c \,.\left\{\frac{d\,y}{d\,x} - \frac{1}{2}\left(\frac{d\,y}{d\,x}\right)^3 - \&c.\right\} = c \,.\, \frac{d\,y}{d\,x},$$

neglecting the higher powers of the quantity $\frac{d\,y}{d\,x}$, which (being the tangent of the inclination of the element A B to the axis) is infinitely small. Similarly the point B will be solicited *from* the axis by the tension c applied at B in the direction B C, whose resolved part in the direction of the ordinate is equal to $c \,.\, \frac{d\,y'}{d\,x'}$. The resolved parts in directions parallel to the axis, being equal and parallel, destroy each other; consequently, the whole force applied at B will be $c \,.\left(\frac{d\,y'}{d\,x'} - \frac{d\,y}{d\,x}\right)$; or, supposing $d\,x$ constant, $c \,.\, \frac{d^2\,y}{d\,x^2}\,d\,x$, tending to increase the value of y.

150. Its equation derived and integrated.

Now the motion of the cord will be the same, whether we regard it as a continuous mass, or compound of detached particles situated at A, B, C, D, &c. and connected by filaments A B, B C, &c. without weight. Thus at B we may conceive to be placed a weight equal to $\frac{AB + BC}{2}$, at C the weight $\frac{BC + CD}{2}$, and so on, that is, neglecting $\left(\frac{d\,y}{d\,x}\right)^2$, simply a constant weight $d\,x$ in each point. This, then, is the mass to be moved by the moving force $c\,\frac{d^2\,y}{d\,x^2}\,d\,x$, and the accelerating force is, therefore, simply $c\,\frac{d^2\,y}{d\,x^2}$. Hence, calling t the time, and regarding $d\,t$ as constant as well as $d\,x$, x and t being independent variables, and putting $2\,g = 9^{\cdot\text{met.}}8088 = 32^{\cdot\text{feet}}18169$, or $g = 16^{\cdot\text{feet}}090845$, we have

$$\frac{d^2\,y}{d\,t^2} = 2\,g\,c \,.\, \frac{d^2\,y}{d\,x^2};$$

or, putting

$$2\,g\,c = a^2; \qquad a = \sqrt{2\,g\,c},$$

$$\frac{d^2\,y}{d\,t^2} = a^2 \,.\, \frac{d^2\,y}{d\,x^2}.$$

This equation is precisely similar to that above obtained for the propagation of Sound along a cylindrical pipe, and its integral will, of course, be of the same form, *viz.*

$$y = F(x + a\,t) + f(x - a\,t.)$$

151. Determination of the arbitrary functions.

The determination of the arbitrary functions in this equation will depend on the conditions we may set out from. Now, first, when the cord is supposed to be of indefinite length, and the part initially disturbed to be *comparatively* very small; and having an indefinite undisturbed portion on either side. In this case, it is evident by the very same reasoning as that of Articles 63 and 64, that a pulse or undulation will run out both ways along the cord from the point of initial disturbance, with a velocity represented by $a = \sqrt{2\,g\,c}$, every molecule of the cord being once agitated during the time the pulse runs over it, and no more. Moreover, a condition similar to that which ensures the single propagation of the pulse when once it has proceeded beyond the limits of the initial disturbance ($x = \pm\,\alpha$) in the theory of Sound, holds good in the present case; for we have

$$\frac{d\,y}{d\,x} = F'(x + a\,t) + f'(x - a\,t)$$

$$\frac{d\,y}{d\,t} = a\,F'(x + a\,t) - a\,f'(x - a\,t).$$

Condition for the single propagation of a wave.

So that on the positive side of the x, when $x > \alpha$, and therefore $x + a\,t = \alpha$, and $F(x + a\,t)$ and $F'(x + a\,t) = 0$, we shall have

$$a\,\frac{d\,y}{d\,x} = -\,\frac{d\,y}{d\,t};$$

which expresses that the tangent of the obliquity of the cord to the axis in its disturbed state, at any point, is proportional to the absolute velocity of that point in its motion, or putting $\theta =$ angle B A a,

$$a \,.\, \tan\theta = -\,v;$$

Reflexion of the wave by an obstacle, as in Sound.

and when this conditon ceases to hold good, as it does when the pulse encounters an obstacle either fixed or less movable than the rest of the cord, it will be either wholly reflected, or divide itself into two, one running back, and producing a species of imperfectly echoed or reflected wave, just as in the theory of Sound.

Since, in the above investigation, c represents a *force* equal to the tension on the same scale that $d\,x$ represents a *weight* equal to that of the element $d\,x$, we have

$$\text{weight of } d\,x : \text{tension} :: d\,x : c.$$

152. Velocity with which a wave runs along a stretched cord.

Hence c represents the length of a portion of the cord whose weight is equal to the tension, and $\sqrt{2\,g\,c}$ the velocity which would be acquired by a body falling freely by gravity through that length. Hence this theorem, *The velocity of a pulse, or undulation propagated along a tended cord, is equal to that which a heavy body would acquire by falling freely through the length of a portion of the cord whose weight is equal to its tension.*

153. Case when one extremity of the cord is fixed.

Let us next suppose the cord attached at one of its extremities to an immovable point, and let the undulation be supposed to reach this point, at which suppose $x = l$, then, whatever be the value of t, $y = 0$, when $x = l$. So that we must have

$$F(l + a\,t) + f(l - a\,t) = 0.$$

Since $a\,t$ may have any positive value, and since on the positive side of the x (at which we have supposed the fixed end situated) $x < l$, therefore $l - x$ is in all cases positive, and therefore may be one of the values of $a\,t$. We may substitute, then, $l - x$ for $a\,t$ in this equation, when we get for positive values of x less than l, and for all negative ones

$$F(2\,l - x) + f(x) = 0; \qquad \text{or } F(2\,l - x) = -f(x). \qquad (p)$$

Now, in general, $$y = F(x + a\,t) + f(x - a\,t).$$

If, then, we make $a\,t = x + \omega$, where ω is any quantity between $+\,\alpha$ and $-\,\alpha$, at which values of x both $f(x)$ and $F(x)$ may be supposed to vanish,

$$y = F(2\,x + \omega) + f(-\,\omega),$$

and if we make $a\,t = 2\,l - x + \omega$, we have

$$y = F(2\,l + \omega) + f(2\,x - 2\,l - \omega),$$

but by (p) $$F(2\,l + \omega) = -f(-\,\omega),$$
so that for the latter value of t we have

$$y = -f(-\,\omega) + f(2\,x - 2\,l - \omega).$$

Now since when $t = 0$, we have $y = F(x) + f(x)$ and $\dfrac{d\,y}{d\,x} = F'(x) + f'(x)$; $\dfrac{d\,y}{d\,t} = a\,\{F'(x) - f'(x)\}$, all these values must vanish unless x lies between the limits $+\,\alpha$ and $-\,\alpha$. Consequently, for all values but those comprised within such limits, we now have $F(x) = 0$ and $f(x) = 0$. From the above equations, then, supposing $x > \alpha$, or $< -\,\alpha$; and, therefore, $F(2\,x + \omega) = 0$, and $f(2\,x - 2\,l - \omega) = 0$, we see that for values of $a\,t$ between $x + \alpha$ and $x - \alpha$, y will have real values; and that when $a\,t$ attains any value between $2\,l - x + \alpha$, and $2\,l - x - \alpha$, y will again have real values, the same as the former, only with contrary signs. Thus the reflected pulse runs back with the same velocity as the direct, and is in all respects similar and equal to it, only that it lies on the opposite side of the axis. A reasoning precisely similar applies to the case of an aërial pulse reflected from the bottom of a stopped pipe, supposed perfectly rigid.

154. Case when both ends are fixed.

If the cord be fixed at both ends, the two pulses into which the initial pulse has separated itself, will each be totally reflected, and will run along the whole length, being reflected again at the other end, and thus run backwards and forwards for ever, at least if we neglect the effect of the stiffness of the cord and resistance of the air; crossing each other at each traverse.

155. In this case the cord assumes a continued vibratory motion.

Suppose the whole length of the cord to be $l + l' = L$, of which l lies on the positive, and l' on the negative side of the origin of the x. That portion of the subdivided primitive pulse which runs towards the positive side of the x will describe the length l in a time $= \dfrac{l}{a}$; being then reflected it will describe the whole length $l + l'$ in a time $\dfrac{l + l'}{a}$; and being again reflected, it will describe l' in a time $\dfrac{l'}{a}$, so that after a time

$$= \frac{l}{a} + \frac{l + l'}{a} + \frac{l'}{a} = \frac{2\,L}{a},$$

it will reach its first starting point; and having been twice inverted by reflexion, will lie now on the same side of the axis it originally was. Similarly, the negative portion of the original pulse will describe l', $l' + l$, and l, and reach its starting point after two reflexions in the time

$$\frac{l'}{a} + \frac{l' + l}{a} + \frac{l}{a} = \frac{2\,L}{a},$$

the same as the other, and will also have recovered its original situation with respect to the axis. Thus at the end of this time the two pulses will precisely reunite, and constitute a compound pulse in all respects similar to the initial impulse. The state of the cord, then, after the lapse of the time $\dfrac{2\,L}{a}$, will (abstracting the effects of resistance, &c.) be precisely what it was at first; and so again, after the lapse of time $\dfrac{4\,L}{a}$, $\dfrac{6\,L}{a}$, &c. the same state will recur, so that if left to itself it will continue to vibrate for ever.

156. Passage from a transitory pulse to a permanent vibration.

Thus we see that what in an indefinite cord was merely a pulse running along it and never returning, becomes, by the reaction of the fixed extremities of a finite one, a regular vibration, in which each molecule repeats its motion to and fro on either side of the axis, at equal intervals, for ever. In the foregoing reasoning no particular assumption has been made respecting the value of a. It has not been supposed small with respect to l, l', and, consequently, the above conclusion applies equally to the case where the initial disturbance is confined to a minute portion of the cord, and where a large portion, or even its whole length, is disturbed at once. Only in the former case the motions of the individual molecules of the cord will be performed by starts interrupted by intervals of absolute rest in the axis. In the latter there will be no moments of rest but those when the direction of the motion changes at the extreme points of their excursions.

157. Time of vibration of a stretched cord.

Hence we conclude that when a stretched cord, whose length $= L$, is struck, or forcibly drawn out of its straight situation into any form and let go, it will continue to vibrate to and fro, and that the time of one complete vibration, after which it resumes its initial state, is represented by $\frac{2\,L}{a} = \frac{2\,L}{\sqrt{2\,g\,c}}$, being equal to the time of a pulse running over double the length of the cord, or to the time in which a body would describe such double length with the velocity acquired by falling down a height equal to the length of a portion of the cord whose weight is the tension.

158. In different cords.

Hence the times of vibration of different cords are, as their lengths directly, and the square roots of the tending forces inversely, and the number of vibrations, *dato tempore*, as the lengths inversely, and the square root of the tensions directly.

159. Prolongation of the figure of the cord on either side of its fixed extremities. Fig. 10.

The equations which express the conditions arising from the immobility of the ends of the cord so far limit the arbitrary functions F and f, that when the figure of the cord between its two extremities is given it may be prolonged beyond them to any extent. To show this, let y_1 represent the ordinate $P_1\,M_1$ of the curve supposed to be continued beyond B, one of the fixed extremities, at a distance, $B\,P_1$, beyond that end equal to B P, the distance from it of the ordinate y, and, for simplicity, suppose $l' = 0$, or let the origin of the x be at the other fixed extremity, A, (fig. 10.) Then we have

$$y = F(x + a\,t) + f(x - a\,t),$$
$$y_1 = F(2\,L - x + a\,t) + f(2\,L - x - a\,t).$$

Now the condition of Art. 153, derived from the fixity of the point B, *viz.*

$$F(2\,L - x) + f(x) = 0,$$

gives, if we write for x successively $x - a\,t$ and $2\,L - x - a\,t$, the following equations,

$$F(2\,L - x + a\,t) + f(x - a\,t) = 0,$$
$$F(x + a\,t) + f(2\,L - a - a\,t) = 0,$$

whose sum is no other than

$$y + y_1 = 0, \text{ or } y_1 = -\,y.$$

Thus we see that the curve A M B will be continued beyond B by merely reversing it from right to left and transferring it to the other side of the axis. Again, if we put y_2 for the ordinate $P_2\,M_2$ at a distance $= x$ beyond C, we have

$$y_2 = F(2\,L + x + a\,t) + f(2\,L + x - a\,t),$$

and

$$\left.\begin{array}{l} F(2\,L + x + a\,t) + f(-\,x - a\,t) = 0 \\ F(-\,x + a\,t) + f(2\,L + x - a\,t) = 0 \end{array}\right\}$$

On the other hand, the condition of the immobility of the point A gives, as we have seen,

$$F(x) + f(-\,x) = 0,$$

in which, writing successively for x, $+\,x + a\,t$, and $-\,x + a\,t$, we get

$$\left.\begin{array}{l} F(x + a\,t) + f(-\,x - a\,t) = 0 \\ F(-\,x + a\,t) + f(x - a\,t) = 0 \end{array}\right\}$$

and subtracting the sum of these from that of the two former, we find ultimately

$$y_2 - y = 0, \text{ or } y_2 = y,$$

so that the portion of the curve $C\,M_2\,D$ is the very same with the first portion A M B. And thus we may go on as far as we please, repeating the same curve alternately in a direct and reverse position, and the same manifestly holds good on the other side of the point A.

160. Origin of nodal points. See fig. 10.

A very simple consideration will show that such ought to be the case; for if we conceive two equal and similar cords, A M B, $B\,M_1\,C$, (fig. 10,) both attached to the same point, B, and vibrating simultaneously, the strain on B, from both their tensions, will be always equal and opposite, provided the curves be so related as above described, and B, therefore, will be retained in equilibrium, independently of its attachment to any extraneous body, so that were it detached, or if the two cords, instead of being fixed to one immovable point, were merely linked together at B, so as to form one cord of double the length, their vibrations would be the same.

161. A cord may have any number of them.

Some curious and important consequences follow from this. And, first, a cord, although vibrating freely, may yet have any number of points, equally distributed at aliquot parts of its whole length, which never leave the axis, and between which the vibrating portions are equal and similar, and lie alternately above and below the axis, and in reversed positions as to right and left. Such points of rest are called nodes or nodal points, the intermediate portions which vibrate are termed *bellies* or *ventral segments*.

162. Division of a vibrating cord into ventral segments vibrating simultaneously.

Secondly, if a string in the act of vibration be touched in any point so as to reduce that point to rest and retain it in the axis, then if, after the contact, it vibrate at all, it will divide itself into a certain number of ventral parts similar and equal to each other and separated by nodes, and each of these will vibrate as if the others had no existence, but instead the nodes were fixed points of attachment. Hence, if L be the whole length of a cord, n the number of ventral segments into which it divides itself, and, therefore, $n - 1$, the number of its nodes, the time of one complete vibration (going and returning) will be $\frac{2\,L}{n\sqrt{2\,g\,c}}$, and the number of vibrations per second will be represented by the reciprocal of this fraction.

163. Production of harmonic Sounds.

Experience confirms this. If the string of a violin, or violoncello, while maintained in vibration by the action of the bow, be lightly touched with the finger or a feather exactly in the middle, or at one-third of the length, it will not cease to vibrate, but its vibrations will be diminished in extent and increased in frequency, and a note will become audible, fainter but much more acute than the original, or, as it is termed, the *fundamental* note of the string, and corresponding in the former case to a double, in the latter to a triple rapidity of vibration. The note heard in the former case being the octave, in the latter the twelfth, above the fundamental tone (See Index, *Musical Intervals.*) If a small piece of light paper, cut into the form of an inverted V, be set astride on the string, it will be violently agitated, and, probably, thrown off when placed in the middle of a ventral segment, while at a node it will ride quietly as if the string were (as it really is at those points) at perfect rest. The Sounds thus produced are termed harmonics.

164. Coexistence of several modes of vibration in one cord.

But, further, any number of the different modes of vibration, of which a cord is thus susceptible, may be going on *simultaneously*, or be, as it were, superposed on each other. This is a consequence of the principle in mechanics of "the superposition of small motions," which, when the excursions of the parts of a system from their places of rest are infinitely small, admits of any or all the motions of which, from any causes, they are susceptible, to go on at once without interfering with or disturbing each other. In the particular case before us it is easily shown, for since the general integral of the equation

$$\frac{d^2 y}{d\,t^2} = a^2 . \frac{d^2 y}{d\,x^2} \qquad \text{is} \qquad y = \mathrm{F}(x + a\,t) + f\,(x - a\,t),$$

where F and f denote arbitrary functions, we may suppose

$$\mathrm{F}\,(x) = \mathrm{F}_1\,(x) + \mathrm{F}_2\,(x) + \mathrm{F}_3\,(x) + \&c.$$

$$f\,(x) = f_1\,(x) + f_2\,(x) + f_3\,(x) + \&c.$$

where F_1, F_2, &c., and f_1, f_2, &c., denote functions equally arbitrary, and we get

$$y = \{\,\mathrm{F}_1\,(x + a\,t) + f_1\,(x - a\,t)\,\} + \{\,\mathrm{F}_2\,(x + a\,t) + f_2\,(x - a\,t)\,\} + \&c.$$

Now each of the expressions within brackets is the integral of an equation exactly similar to the original one. Therefore, if we put

$$\frac{d^2 y_1}{a\,t_2} = a^2 . \frac{d^2 y_1}{d\,x^2}; \quad \frac{d^2 y_1}{d\,t^2} = a^2 . \frac{d^2 y_2}{d\,x^2}; \ \&c.$$

we shall have

$$y = y_1 + y_2 + y_3 + \&c.$$

Thus, if the several particular modes of vibration, $y = y_1$ $y = y_2$, &c., be possible, $y = y_1 + y_2 +$ &c. will also be possible: the ordinate of the curve into which the cord at any moment forms itself in virtue of the compound vibration will be the sum (algebraically understood) of the ordinates it would have in virtue of each simple one, separately: the compound curve will be formed by first constructing on the abscissa, as an axis, any one of the simple ones, then on that curve, as an abscissa, any other, on the new curve thence arising any other, and so on.

165. Fig. 11. Curves arising from superposition of several coexistent vibrations.

Hence it is evident that if we suppose the curve, whose ordinate is y_1, to be of the form, fig. 11, (a) having no node, and that, whose ordinate is y_2, to have, for instance, one node, as fig. 11, (b) the corresponding modes of vibration, when coexisting, will produce a curve, such as (c). On these we may superpose a third mode of vibration, where the string divides itself into three ventral segments, as (d), and the result will be a curve, such as (e), and so on to any extent. The reader may exercise himself in tracing the variations of form in these curves as they go through the several phases of their periodic excursions during one complete period of a vibration of the whole string as one cord.

166. Harmonic Sounds heard with the fundamental Sound.

Experience again confirms this result of theory. It was long known to musicians that, besides the principal or fundamental note of a string, an experienced ear could detect in its Sound when set in vibration, especially when very lightly touched in certain points, other notes, related to the fundamental one by fixed laws of harmony, and which are called, therefore, harmonic sounds. They are the very same which, by the production of distinct nodes, may be insulated, as it were, and cleared from the confusing effect of the coexistent Sounds, as in Art. 163. They are, however, much more distinct in bells, and other sounding bodies, than in strings, in which only delicate ears can detect them.

167. The monochord.

The monochord is an instrument well adapted to exhibit these and all other phenomena of vibrating strings. It is nothing more than a single string of catgut fixed at one end immovably, and at the other strained over a well-defined edge, which effectually terminates its vibrations, either by a known weight or by screws. A similar well-defined edge is also interposed between its fixed end and the vibrating portion, and the interval between the two edges is graduated into aliquot parts, or in any other convenient way, and it is provided with a movable *bridge*, or piece of wood capable of being placed at any division of the scale, and abutting firmly against the string so as to stop its vibrations, and divide it into two of equal or unequal lengths, as the case may be.

168. Applied to measure the vibrations of a given note.

By the aid of this instrument we may ascertain the number of vibrations which belongs to any assigned musical note, or which correspond to the notes of any musical instrument, as a piano-forte, &c. For when we have ascertained the weight of a known length of the catgut, of which the string is formed, and the weight which must be applied to stretch the cord, so as to make its fundamental tone coincide with any given note, (as the middle C of a piano-forte,) then by the formula $\frac{\sqrt{2gc}}{2L}$ we know the number of complete *vibrations* going and returning, and by the formula $\frac{\sqrt{2gc}}{L}$ the number of oscillations from rest on one side of the axis to rest on the other, that is, the number of impulses made on the ear per second corresponding to that fundamental tone. To determine the same for any note *sharper*, *higher*, or more *acute* than the fundamental note, we have only to apply the bridge, and move it backwards and forwards till the sound of the vibrating part of the string is *in unison with* that of the note to be compared, of which the ear judges with the greatest precision; then if the length of this part, read off on the divided scale, be called l, the number of its vibrations per second will be to that of the whole string $L :: L : l$, and is therefore known.

169. Sympathy between cords which have a mode of vibration in common.

The production of harmonic Sounds from cords, and their division into aliquot parts, was first noticed, in 1673, by Wallis, (*Opera* J. Wallisii, fol. ii. p. 466, cap. cvii.,) but the subject remained unattended to till taken up by Sauveur, in a valuable Memoir, published among those of the French Academy for 1701, which first put this part of the doctrine of Acoustics in a clear point of view. The contact of a solid obstacle is not the only means of producing them. If two cords equally tended, and in all other respects similar, but one only half, one third, or other aliquot part of the length of the other, be placed side by side, and the shorter be struck or sounded, the vibration will be communicated to the longer by the intervention of the air, which will thus at once be thrown into a mode of vibration, in which the whole length is divided into ventral segments, each equal to the shorter string. To understand how this may happen, let us conceive first two strings of equal length, one at rest the other vibrating, and let them be placed parallel, and side by side, then the sonorous pulses diverging at any instant from each point of the moving string, will arrive at once at each corresponding point of the other. The aerial molecules in their progress, while condensed, will press on the string and give it a very slight motion in their own direction; in their retreat they will be followed by the string, whose vibrations by hypothesis are synchronous with their own, but it will not follow them so fast as they retreat, and it will be, therefore, urged and accelerated by those behind. It will, however, come to rest, in its furthest point of excursion, at the same time with the aerial molecules, when its elasticity will begin to urge and accelerate it in the contrary direction. But now also the direction of the motion of the air has changed, and again conspiring with that of the cord still continues to accelerate it, and so on, till, after a very great number of repetitions of this process, the cord will be set in full vibration and will become itself a source of Sound. But its Sound will always be much fainter than that of the original vibrating cord, for this reason, *viz.* that its acquired motion is perpetually dissipated, *laterally*, into the surrounding air, for no cord is so exactly uniform, or so equally tended in every part of its transverse section, that it *can* vibrate rigorously in one plane. Hence it will inevitably begin to rotate, or to describe vibrations whose plane is continually shifting, (see Art. 177,) and thus it will throw off laterally a great part of the motion it receives from the air; just as a body exposed to the radiation of a hot fire never acquires a temperature equal to that of the fire, part of the heat communicated being dissipated by lateral radiation.

170. Establishment of a mode of vibration by sympathy illustrated.

Just as a small pull, repeated exactly in the time of its natural swing, will raise a great bell, or a trifling impulse a heavy pendulum, so the molecules of the air, in a state of sonorous vibration, will impress on any body *capable of vibrating in their own time* an actual vibratory motion, and if a body be susceptible of a number of modes of vibration performed in different times, *that mode only will be excited which is synchronous with the aerial pulsations.* All other motions, though they may be excited for a moment by one pulsation, will be extinguished by a subsequent one. Hence, if two cords have any mode of vibration in common, that mode may be excited by sympathy in either of them when the other is sounded, and that only. For example, if the length of one cord be to that of the other as 2 : 3, and if either be set vibrating, the mode of vibration, corresponding to a division of the former into two, and of the latter into three ventral segments, will, if it exist in the one, be communicated by sympathy to the other. Nay, if it do not originally exist, it will, after a while, establish itself; for all accidental circumstances which may favour such a division have their effects, however minute, continually preserved and accumulated, till at length they become sensible.

171. Remarkable effects of sympathetic communication of vibration.

In the vibrations of cords, which from their small surface can receive but a trifling impulse from the air, the Sounds and motions excited by this sort of sympathetic communication are feeble, but in vibrating bodies, which present a large surface, they become very great. It is a pretty well authenticated feat performed by persons of clear and powerful voice, to break a drinking-glass by singing its proper fundamental note close to it. (See Chladni, *Acoust.* § 224.) Looking-glasses also are said to have been occasionally broken by music, the excursions of their molecules in the vibrations into which they are thrown being so great as to strain them beyond the limits of their cohesion.

172. Numerical comparison of the above theory with experiment by Weber.

The coincidence of the theory above stated, of the propagation of a wave along a stretched cord, with experiment, has been put to careful trial by Weber. (See his *Wellenlehre auf Experimente Gegrundet*, 8vo. Leipsig. 1825, p. 460, a most instructive work.) He stretched a very equal and flexible cotton thread, 51 feet 2 inches in length, weighing 864 grains, horizontally, by a known weight. The thread was struck at 6 inches from one end at the instant of letting go a stop-watch of peculiar and delicate construction, marking thirds, (sixtieths of seconds,) whose motion was instantaneously arrested when the wave had run a certain number of times over the length of the string backwards and forwards. The mean of a great many observations, agreeing well with each other, gave as follows:—

Tension in Grains.	Length run over by the Wave.	Time of its description in Thirds.	Time of running over the length 102 *f.* 4 *in.* in Thirds, by observation.	The same time calculated from the formula $V = \sqrt{2gc}$.
10023	102*f.* 4*in.*	46	46	46·012
10023	204 8	92	46	46·012
10023	409 4	184	46	46·012
33292	409 4	99	24·72	25·246
69408	409 4	65	16·25	17·485

A completer coincidence could not have been wished for. The slight discrepancies may, perhaps, arise from the want of uniformity in the tension of so long a thread, which would, of course, form a catenary of sensible curvature. We should observe, however, that M. Weber has reckoned here the weight (864 grains) of the thread as part of the tension, a proceeding whose legitimacy may be questioned.

173. Ocular evidence of the transition from progressive pulses to a permanent state of vibration.

The way in which the permanent or vibratory oscillations of a cord arise by reflexion at its fixed extremities from a wave propagated along it progressively, may be rendered a matter of ocular inspection if we take a long and pretty thick cord, fasten it at one end, and holding the other in our hands, give it a regular motion to and fro, transverse to the length of the cord. Progressive waves will thus arise, which, as soon as they reach the fixed end, and are reflected, will be observed to interfere with those still on their way, and, as it were, to arrest them, producing a series of nodes and ventral segments, whose number will depend on the tension and frequency of the alternate motion communicated to the movable end. In this arrangement the continual periodic renewal of the primary impulse by the hand supplies the place of a reflecting obstacle at that end.

174. Difference in the quality of the tone of stringed instruments whence arising. Fig. 12.

The pitch of the Sound of a vibrating string depends only on the number of vibrations made *dato tempore*, its quality will depend partly on the nature of the string, and especially on its equality of thickness, besides which, much may depend on the form and extent of the wave excited, or of the curve into which it is thrown. In instruments, like the violin or violoncello, played with a bow, or the guitar or harp, where the string is drawn softly out of its position and suddenly let go, this curve is, probably, single, and occupies the whole length of the string; but in the piano-forte, where the strings are struck, near one extremity, with a sharp sudden blow, there can be little doubt that the vibration consists in an elevation or bulge, more or less extensive, running backwards and forwards. Fig. 12 represents the different phases of a single complete vibration of a string so struck. The first wave (1) is a single elevation, it divides in (2) into two running contrary ways; in (3) that nearest the end A is reflected and takes a reversed position; in (4) they advance the same way towards B; in (5) the unreflected portion reaches B, is there reflected and reversed, as in (6). In (7) it meets and coincides with the former reflected portion, there forming a depression equal and similar to the original elevation in (1), and as far distant from the end B as the former from A. After this the same steps are repeated in the reverse direction, till the original elevation is reproduced again, as in (1). The waves, however, must be supposed to bear a much more considerable ratio to the whole string than in the figure. It is evident that the magnitude of this ratio must influence the quality of the tone, and thus a difference of character in the tone, according as the keys are struck with quick short brilliant blows, or gently pressed, and the duration of the contact of the hammers with the strings prolonged for an instant of time, giving rise to a more moderate but sustained *tenuto* effect, by bringing a larger portion of the string, or even the whole into motion at once.

Phases of a vibration traced.

175. But whether the portion disturbed at once be large or small, whether it occupy the whole string, or run along it like a bulge in its line, whether it be a single curve, or composed of several ventral segments with intervening nodes, we must never lose sight of the fact that the motion of a string with fixed ends is no other than an undulation or pulse continually *doubled back on itself* and retained constantly within the limits of the cord, instead of running out both ways to infinity.

176. Vibrations out of one plane. Forms of orbits described exhibited. Fig. 13.

It very seldom (for the reasons mentioned in Art. 170) can happen that the vibrations of a string actually lie in one plane. Most commonly they consist of rotations more or less complicated, except when produced by the sawing of a bow across the string, when they are forcibly limited to the plane of motion of the bow. The real form of the orbit described by any molecule may be made matter of ocular inspection, by letting the sun shine through a narrow slit so as to form a thin sheet of light. Let a polished wire be placed so as to penetrate this sheet perpendicularly to its plane, and the point where it cuts the plane will, at rest, be seen as a bright speck, but when set vibrating it will form a continued luminous orbit, just as a live coal whirled round appears as a circle of fire. Fig. 13 exhibits specimens of such orbits, observed by Dr. Young.

177. A very curious case of a mode of vibration, by which a string may be made to produce a Sound graver than its fundamental tone, is mentioned by M. Biot. If an obstacle be placed below the middle point of a vibrating string so as just to touch, but not to press against it, and the string be then drawn up vertically and let go, it will strike at every oscillation upon this obstacle, and bend over it, as in fig. 14, at every blow; thus resolving itself into two, of half the length. Thus the first semi-oscillation will be performed as a whole, the

next as a subdivided string. Let unity represent the time of one complete oscillation from rest to rest of the whole string; then will the times in which the different phases of the motion now in question are performed be as follows:

From the position A B C to the straight line A C.... $= \frac{1}{2}$.
From the position A C to the position A E D, D F C $= \frac{1}{4}$.
Back to the straight line .... $= \frac{1}{4}$.
Back to the original position A B C.............. $= \frac{1}{2}$.

$$\text{Sum} = \tfrac{1}{2} + \tfrac{1}{4} + \tfrac{1}{4} + \tfrac{1}{2} = \tfrac{3}{2}.$$

Thus the interval between two consecutive blows made by the string on the bridge is $\frac{3}{2}$ of the time of oscillation of the string as a whole, from rest on one side of the axis to rest on the other, or of the impulses made by it on the ear when so vibrating. Hence, the blows on the bridge will be heard as a continued note, (though extremely harsh and disagreeable,) graver than that of the string vibrating as a whole, by the musical interval called a fifth. (See Index, *Musical Intervals.*)

§ III. *Of the Vibrations of a Column of Air of Definite Length.*

178. **Analogy between vibrations of air in a pipe and those of a stretched cord.**

The general equation representing the motions of the molecules of a tended cord of indefinite length is, as we have seen, precisely similar in its form, and in that of its complete integral, to that of the particles of air in a sounding column. There subsists, of course, a perfect analogy between the two cases, and, *mutatis mutandis*, all propositions which are true of a vibrating cord are also true of a vibrating cylindrical volume of air.

179. **Transition from a propagated pulse to a permanent vibration.**

Thus, if such a cylindrical column be enclosed in a pipe, whose length $= l + l' = \mathrm{L}$, stopped at both ends by perfectly immovable stoppers, and if we suppose any single impulse communicated to one of its sections at the distance l from one of its extremities (A), this will immediately divide itself into two pulses running opposite ways; they will be totally reflected at the two extremities, the one, after describing the space l before and l' after reflexion, will meet the other which has described l' before and l after reflexion, at a distance $= l$ from the other extremity B, and produce a compound agitation in the section at that place similar to the primitive disturbance; thence the partial pulses will again diverge, and after each undergoing another reflexion will again unite in their original point of departure, constituting a repetition of the first impulse, and so on, till the motion is destroyed by friction and by the imperfect fixity and rigidity of the stoppers, allowing some of it to pass into them and be lost at each reflexion.

180. **Effect of a permanent vibratory initial impulse.**

But if the section first set in motion be maintained in a state of vibration synchronous with the return of the reflected pulse, it will unite with and reinforce it at every return, and the result will be a clear and strong musical Sound resulting from the exact combination of the original periodic impulse with all its echos. This will be transmitted through the pipe to the outer air, and thus dissipated and lost.

181. **Simplest mode of vibration of the air in a pipe closed at both ends. Analogy with the corresponding case of a stretched cord.**

For simplicity, let us suppose the section primitively set in vibration and so maintained, to be situated just in the middle of the pipe. Then, when once the regular periodic pulsation of the contained air is established, it is evident that the motion of the column will consist of a constant and regular fluctuation to and fro within the pipe of the whole mass, the air being always condensed in one half of the pipe while it is rarefied in the other. The greatest excursions from their place will be made by the molecules in the middle, while those at the extremities, being constantly abutted against the stoppers, remain unmoved, and the excursions made by each intermediate molecule will be greater the nearer it is to the middle. On the other hand, the rarefactions and condensations are greatest at the extremities, and diminish as we approach the middle of the pipe, where there is neither condensation nor rarefaction. The analogy of this case with the case of the vibrating cord will be evident if we consider that the condensation in the former is represented by the angle of inclination of the vibrating curve to its abscissa in the latter, and that the mode of vibration now contemplated in the aerial molecules is analogous to that of a cord vibrating as a whole, and having its two halves symmetrical.

182. **Subdivision of a vibrating column by nodes. Figs. 15, 16.**

In the same way as a vibrating cord is susceptible of division into its several aliquot parts all vibrating simultaneously, so may the aerial column in our stopped pipe vibrate in distinct ventral segments. The manner in which this may take place will be evident on inspection of figs. 15 and 16, where the arrows denote the directions of the motions of the vibrating molecules, and where we see the immobility of the nodal sections is secured by the equal and opposite pressures of the molecules on either side of them. At these nodal sections, too, the same thing holds good as at the stopped extremities, their molecules remain constantly at rest while yet they undergo greater vicissitudes of compression and dilatation than those in any other parts of the column.

183. **Coexistence of several modes of vibration.**

Precisely, too, as in the vibrations of strings, any number of these modes of vibration may go on simultaneously. Such combined modes may be produced by an expert flute player, by a nice adjustment of the force of his breath; at least the octave of any note may be obtained without difficulty, and distinctly heard with the fundamental tone.

184. **Vibration of air in a pipe open at one end.**

Half way between two nodes (regarding the stopped ends as nodes) the condensations and rarefactions are evanescent, and the amplitudes of the molecular excursions are at a maximum. Now at such a point let us conceive a narrow ring of the cylindrical pipe in which the vibrating column is contained to be cut away, so as to open a free communication with the outer air. There will be no tendency for air to pass in or out, because the air within is constantly, at these points, in its natural state as to density; neither will its motion be impeded, being parallel to the axis of the column and without any lateral bias. The detachment then of such a ring will no way alter the vibrations of the column, nor, *a fortiori*, will the opening of a hole in the pipe at this place affect them. Suppose, now, at this hole, a vibrating body placed, whose vibrations are executed in equal times with those in which the excursions to and fro of the included aerial sections are performed in the stopped pipe. They will be communicated to them, and thus the Sound of the pipe will be excited and maintained. Such an aperture is called an *embouchure.*

185. Case where the vibrations are excited by a vibrating disc.

But let us now conceive the one half (A) of the pipe entirely removed, and in its place a disc substituted exactly closing the aperture, and maintained, by some external cause, constantly in a state of vibration, such, that the performance of one complete vibration, going and returning, shall exactly occupy as much time as a sonorous pulse would take to traverse the whole length of the stopped pipe (A + B), or double that of the open one (B). Its first impulse on the air will be propagated along the pipe (B) and reflected at the stopped end, and will again reach the disc just at the moment when the latter is commencing its second impulse. But the absolute velocity of the disc in its vibrations being excessively minute compared with that of Sound, the reflected pulse will undergo a second reflexion at the disc as if it were a fixed stopper. It will, therefore, in its return exactly coincide and conspire with the second original impulse of the disc, and the same process being repeated on every impulse, each will be combined with all its echos, and a musical tone will be drawn forth from the pipe vastly superior to that which the disc vibrating alone in free air would produce. This is, in fact, the simplest instance of the *resonance* of a cavity, of which more hereafter. (See Index, *Resonance.*) Now, it is manifestly of no importance whether the pulses reflected from the closed end of the pipe (B) undergo a second reflexion at the disc, and are so returned back by the pipe, or whether we regard the disc as penetrable by the pulse, (*i. e.* a mere imaginary vibrating section,) and suppose the pulse to run on and be reflected at the extremity of the other half (A) of the bisected pipe (A + B), and on its return again to pass freely through the disc and be again reflected at the stopped extremity of (B). The Sounds produced will be the same, on the principle of the superposition of vibrations. Thus we see that the fundamental Sound of a pipe open at one end is the same with that of a pipe closed at both ends, and of double the length.

186. How performed in practice.

The mode here supposed of exciting and maintaining the vibrations of a column of air in a pipe is easily put in practice. Let any one take a common tuning-fork and on one of its branches fasten with sealing-wax a circular disc of card of the size of a small wafer, or sufficient nearly to cover the aperture of a pipe. The sliding joint of the upper end of a flute, with the mouth-hole stopped, is very fit for the purpose; it may be tuned in unison with the loaded tuning-fork (a C fork) by means of the movable stopper, or the fork may be loaded till the unison is perfect. If the fork be then set in vibration by a blow on the unloaded branch, and the disc be held close over the mouth of the pipe, as in fig. 16, a note of surprising clearness and strength will be heard. Indeed, a flute may be made to "speak" perfectly well by holding close to the embouchure a vibrating tuning-fork while the fingering proper to the note of the fork is at the same time performed. We shall have further occasion to refer to this point. (*Resonance,* Index.)

Fig. 16.

187. Action of a reed.

But the most usual means of exciting the vibrations of a column of air in a pipe is by blowing into, or rather over it, either at its open end or at an orifice made for the purpose at the side, or by introducing a small current of air into it through an aperture of a peculiar construction called a *reed,* provided with a "tongue" or flexible elastic plate which nearly stops the aperture, and which is alternately forced away by the current of air and returns by its elasticity, thus producing a continual and regularly periodic series of interruptions to the uniformity of the stream, and, of course, a Sound in the pipe corresponding to their frequency. Except, however, the reed be so constructed as to be capable of vibrating in unison, or nearly so, with, at least, one of the modes of vibration of the column of air in the pipe, the Sound of the reed only will be heard, the resonance of the pipe will not be called into play, and the pipe will not *speak;* or will speak but feebly and imperfectly, and yield a false tone.

188. Excitement of vibrations by blowing over an orifice.

But of reeds more hereafter; (see Index, *Reeds;*) at present let us consider what takes place when the vibrations of a column of air are excited by blowing over the open end of a pipe or an aperture in its side. To do it effectually the air must be directed in a small current, not *into,* but *across* the aperture, as in fig. 18, so as to graze the opposite edge. By this means a small portion will be caught and turned aside down the pipe, thus giving a first impulse to the contained air and propagating down it a pulse in which the air is slightly condensed. This will be reflected at the end as an echo, and return to the aperture where the condensation goes off, the section condensed expanding into the free atmosphere. But in so doing, it lifts up, as it were, and for a moment diverts from its course the impinging current, and thus, while it passes, suspends its impulse on the edge of the aperture. The moment it has escaped the current resumes its former course, again touches the edge of the aperture, creates there a condensation, and propagates downwards another condensed pulse, and so on. Thus the current passing over the aperture is kept in a constant state of *fluttering* agitation, alternately grazing and passing free of its edge, at regular intervals, equal to those in which a sonorous pulse can run over twice the length of the pipe; or, more generally, in which the condensations and rarefactions recur at its aperture in virtue of any of the modes of vibration of which the column of air in the pipe is susceptible.

Fig. 18.

189. Practical difference between vibrations of air in an open pipe and those of a stretched cord.

In general, wherever there is a communication opened between the column of air in a pipe and the free atmosphere, that point will become a point of maximum excursion of the vibrating molecules, or the middle of a ventral segment. In such a point the rarefactions and condensations vanish, the air reducing itself constantly to an equilibrium of pressure with the free atmosphere with which it is in contact. Hence, if the pipe speak at all, it will take such a mode of vibration as to satisfy this condition, but, consistently with this, it may divide itself into any number of ventral segments. But here there is a point of practical difference between the affections of a vibrating aerial column and those of a tended cord. The tension of the cord can only be maintained steadily *in practice,* by fixing its two ends; so that the case of one extremity fixed, the other free, can have no existence but in imagination, where the cord may be conceived as of indefinite length in one direction, so that the outrunning pulses may lose themselves, or, at least, never return. It is true they might be stifled by wrapping one end of a very long cord in cotton, but whether, under such circumstances, any mode of producing and maintaining an initial periodical impulse sufficiently regular to produce musical Sounds could be found remains to be tried. The nearest approach to the case in question is when one end of a long cord is held in the hand and agitated while the tension is maintained, as in Art. 173.

190. Times and modes of vibration in pipes open at both ends. Fig. 19.

In cords with fixed extremities, however, all the ventral segments must, of necessity, be complete, no half segments can exist. In pipes it is otherwise. The air in a pipe closed at one end vibrates as a half, not the whole of such a segment. It is owing to this that a pipe open at both ends can yield, if properly excited, a musical Sound. The column of air in it vibrates in the mode represented in fig. 19, where there is a node in the middle and each ventral segment is only half a complete one. In general it is easy to represent, in an algebraic formula, the time of vibration, or the number of vibrations per second corresponding to any mode of vibration. For, first in a pipe open at both ends let the number of nodes be n, then there will be $n-1$ complete ventral segments between them, as in fig. 20, and a moiety of one at each end. If, then, we call L the whole length of such a pipe in feet, V the velocity of Sound in feet per second, the length of one complete ventral segment will be $\frac{L}{n}$. This length is traversed by a sonorous pulse in a time $\frac{1}{n} \cdot \frac{L}{V}$, and this is the time of vibration of the middle section of it to which the Sound corresponds. The pipe, then, vibrating according to this mode, will yield a Sound whose pitch is that of a cord making $n \cdot \frac{V}{L}$ vibrations per second; and the series of tones it can produce is expressed by the following series of numbers of vibrations,

Fig. 20.

$$1 \cdot \frac{V}{L}; \quad 2 \cdot \frac{V}{L}; \quad 3 \cdot \frac{V}{L}, \text{ \&c.}$$

191. In pipes closed at one end. Fig. 21.

In the case of a pipe closed at one end, the stopped end must be regarded as a node. (Fig. 21.) Calling the whole number of nodes, thus included, n, the number of complete ventral segments will be $n-1$, and one half segment will terminate at the open end. Therefore $\frac{L}{2(n-1)+1}$, or $\frac{L}{2n+1}$, will be the number of such halves contained in the length L, and $\frac{2L}{2n+1}$ will, therefore, be the length of each complete one; so that each will make $\frac{2n+1}{2} \cdot \frac{V}{L}$ vibrations in one second, and thus the series of tones such a pipe can yield will be expressed by the series of vibrations,

$$\frac{1}{2} \cdot \frac{V}{L}; \quad \frac{3}{2} \cdot \frac{V}{L}; \quad \frac{5}{2} \cdot \frac{V}{L}, \text{ \&c.}$$

192. In pipes closed at both ends.

Lastly, the number of nodes, including the two stopped ends of a pipe closed at both ends, being n, the number of segments (all complete) into which it will be divided will be $n-1$, and the length of each will be $\frac{1}{n-1} \cdot \frac{L}{V}$; so that the series of Sounds, of which such a pipe is susceptible, is represented by the series of vibrations,

$$1 \cdot \frac{V}{L}; \quad 2 \cdot \frac{V}{L}; \quad 3 \cdot \frac{V}{L}, \text{ \&c.}$$

Taking, therefore, unity for the number of vibrations per second in the fundamental tone, the series of harmonics will run as follows:

In a pipe stopped at both ends	1, 2, 3, 4, 5, &c
———— open at both ends	1, 2, 3, 4, 5, &c.
———— stopped at one end, open at the other....	1, 3, 5, 7, 9, &c.

It being recollected, however, that in the last series the fundamental note 1 is an octave lower than in the others, *i. e.* performs its vibrations only half as rapidly.

193. Method of exciting these different modes of vibration.

To produce these Sounds by blowing into a pipe, it is only requisite to begin with as gentle a blast as will make the pipe speak, and to augment its force gradually. The fundamental tone will be heard first; and as the strength of the blast increases, will grow louder, till at length the tone all at once starts up an octave, *i. e.* the interval between notes whose vibrations are as 1 : 2. By blowing still harder, the next harmonic, 1 : 3, or as it is called in Music, the octave of the fifth, or the *twelfth* of the fundamental tone, is heard; but no adaptation of the embouchure, or force of the wind, will produce any note intermediate between these. The next harmonic is 1 : 4, and corresponds to the double octave, or *fifteenth* of the fundamental tone; and the next, or 1 : 5, to the *seventeenth*, or major third above the double octave. (See the explanation of these terms in Art. 210, *et seq.*) The next, 1 : 6, corresponds to the *nineteenth*, or double octave of the fifth, and so on. All the notes here enumerated are very readily produced on the flute, without changing the fingering, from the lower C or D upwards, by merely varying the force of the blast, and a little humouring the form of the lips and their position with respect to the embouchure. The reader may consult on this subject D. Bernouilli, *Sur le Son et sur les Tons des Tuyaux d'Orgues, Mém. Acad. Paris,* 1762; in which the true theory of wind-instruments is

Series of harmonic tones of a pipe or flute.

first clearly stated, though pointed out by Sauveur, in a Paper published in the *Mém. de l'Acad.* 1701. Also a very instructive Paper by Lambert, *Observations sur les Flûtes, Mém. Acad. Berl.* 1775. (See also Euler, *De Motu Aeris in Tubis Petrop. Comm.* xvi. and Lagrange's Memoirs already cited, *Mél. de Turin*, i. and ii.) M. Biot, by adapting an organ bellows to regulate the blast, and give it the requisite force and uniformity, succeeded in drawing from a pipe furnished with a proper embouchure, not only these, but also the notes represented in the harmonic series by 7, 8, 11, and 12, but not 9 or 10, (the reason of which vacancy does not appear.) *Traité de Physique*, ii. 126.

194. **Rationale of the action of the embouchure in exciting harmonic sounds.** The rationale of the continual subdivision of the vibrating column, as the force of the blast increases, is very obvious. A quick sharp current of air is not so easily driven aside by an external disturbing force; and when so driven, returns more rapidly to its original course, than a slow and feeble one. A quick stream, when thrown into a ripple by an obstacle, undulates more rapidly than a slow one. Consequently, on increasing the force of the blast, a period will arrive when the current *cannot* be diverted from its course and return to it so *slowly* as is required for the production of the fundamental note. The next higher harmonic will then be excited, until, the force of the blast increasing, it becomes once more incapable of sympathizing with the excursions of the aerial molecules at the embouchure in this mode of vibration, and so on.

195. **Velocity of Sound concluded from the note sounded by a given pipe. Velocity of Sound in gases thence deduced.** If we know the velocity of Sound in the column of air included in a pipe, the length of the pipe, and the mode of vibration, the number of vibrations may be computed, and *vice versâ*, if we know the number of vibrations made in a given pipe, vibrating in a known manner, we may thence compute the velocity of Sound. This furnishes a ready and simple method of determining the velocity of Sound in any gas or vapour. We have only to fill a pipe first with air, and then with the gas or vapour in question; and having set them vibrating by any proper means, so as to draw forth their fundamental tone, to compare this with a monochord, or with any musical instrument possessing a regular scale or progression of notes where vibrations are known; and having thus ascertained the number of vibrations per second performed by a column of each medium, the velocities of Sound in the respective cases will be in the direct ratio of their numbers. It is thus that Chladni, and, more lately, Vanrees, Frameyer, and Moll have ascertained the velocities of Sound in the various media enumerated in Art. 82.

196. **The column of air, not the pipe, is the sounding body.** That it is really the air which is the sounding body in a flute, organ-pipe, or other wind-instrument, appears from the fact, that the materials, thickness, or other peculiarities of the pipe, are of no consequence. A pipe of paper and one of lead, glass, or wood, provided the dimensions be the same, produce, under similar circumstances, exactly the same tone as to *pitch*. If further proof were necessary, the difference of pitch produced by filling the pipe with different gases would place the point beyond a doubt. If the *qualities* of the tones produced by different pipes differ, this is to be attributed to the friction of the air within them, setting in feeble vibration their own proper materials.

197. **Influence of the embouchure of a pipe on its pitch.** The influence of the size and situation of the embouchure of a pipe, and still more of the manner of exciting the vibrations of the sections of the aerial column near that place, are very material in determining the pitch of the tone uttered. Were it possible to excite the aerial column to vibration by setting in motion a single section of it by a wish, we should obtain, doubtless, Sounds always strictly conformable to the length of the pipe and its harmonic subdivisions as above; but, in fact, the vibrating column of air and the extraneous body (be it reed, tuning-fork, or stream of air) which sets it in motion exercise on each other a mutual influence; they vibrate as a system, (see Index, *Vibrations of a System of Bodies*,) and the resulting tone may be made to deviate more or less from the pure fundamental tone of the pipe, according to the greater or less mass of matter, and the fixity of the vibrations of the apparatus by which the pipe is made to *speak*. When, for example, the cause of vibration is the mere passage of a stream of air over the orifice, whose motions are almost entirely commanded by the condensations and rarefactions within the pipe, (Art. 194,) but little deviation can take place. Yet, by varying the inclination of the stream, (as in the case of the flute by turning the mouth-hole more inwards or outwards with respect to the lips,) and thus giving it a greater or less obliquity to the edge against which it strikes, we may alter the note very sensibly, as is known to all flute-players, who use this means of humouring the instrument, and playing in tune in keys which would otherwise be insupportable.

198. **Diapason organ-pipe.** In the diapason organ-pipe, whether open or stopped, a stream of air is admitted at the vertex of the conical lower end, but is prevented from passing through the whole length of the pipe by a plate of metal separating the cone from the pipe, and is forced to escape through a narrow slit transverse to the axis of the pipe, in doing which it strikes against the edge of a thin piece of lead, or other flexible metal. This disposition will be understood by inspection of the figure 22, in which B B is the organ-pipe, and *b c b* the conical appendage at its foot by which the air is admitted. (Fig. 22.) One side of the pipe B L M is flattened and a little bent inwards, and at L a narrow slit is made, just opposite to the lower edge of which is the plate of metal *b b*, which has its edge nearest the orifice a little cut away, so as not quite to fill the whole section of the pipe, but to leave a narrow slit parallel to the slit F F in the side of the pipe. Through this the air admitted at *c* escapes, and is directed in a thin sheet against the upper lip L of the lateral slit; against which it breaks, as described in Art. 188, and sets in vibration the column of air contained in the pipe. **Its harmonics.** If the stream of air be too strong the pipe will yield the octave and harmonic of its fundamental note, forming the series 1, 2, 3, 4, &c. If, on the other hand, the current of air remaining constant, the breadth of the slit through which the air escapes be diminished, according to the experiments of MM. Biot and Hamel, harmonics will also be produced, but in the progression 1, 3, 5, 7, &c. the octaves of the fundamental tone and of all the others being entirely wanting.

199. **Reed-pipes.** In reed-pipes, or those in which the vibrations are excited and maintained by passing a current of air into the pipe through a reed, (Art. 187,) the influence of the reed on the pipe is very great. The most perfect and pure tone is produced, of course, when the reed and the pipe separately are pitched in unison, but a considerable latitude in this respect exists; and within certain limits, depending on the mass and stiffness of the reed, as

compared with the dimensions of the pipe, a power of mutual accommodation subsists, and a mean tone is produced, less powerful and less pure and pleasing, however, as the pipe is more forced from its natural pitch, until it ceases to sound altogether, and the note produced, if any, is that of the reed alone. In this respect there is, however, a great difference in pipes of different sizes. In large organ-pipes the reed vibrates with nearly the same freedom as in the open air, and will, therefore, *speak* when the pipe has ceased to resound; but in small and narrow pipes, as in oboes, and other similar wind-instruments, a much closer correspondence between the pitches of the reed and pipe is required, or the reed will not vibrate. Messrs. Biot and Hamel adapted to a glass pipe a reed of the ordinary construction represented in fig. 23, in which the vibrating tongue L (by whose oscillations the opening of the reed at R is alternately opened and closed) could be lengthened or shortened at pleasure by thrusting in or withdrawing a wire F *f*, which bears with a slight spring against the tongue at *f*. The blast of wind being maintained constant, the reed was made to yield its gravest note, by withdrawing the wire as far as possible, after which, by pushing it in, the pitch of the reed was gradually raised. It was observed then that the tone of the pipe grew constantly more acute, but that after a certain point, it began to diminish in intensity, till at length no Sound could be heard. At this point, the tongue of the reed, being narrowly examined through the glass, was observed to be still in rapid vibration; but its vibrations were performed entirely in the air, so as not to strike upon and close the orifice. A constant passage then being left for the air, the vibrations of the pipe could not be excited. But this state of things continued only so long as the tongue was of that precise length. The moment the wire was pushed in by the smallest quantity, the Sound sprung forth anew of a pitch still corresponding with the shortened state of the tongue.

Mutual influence of the reed and pipe. Fig. 23. Construction of a reed, And its manner of vibrating.

200. Influence of the form of the pipe on the Sound. Fig. 24. Fig. 25. Fig. 26.

The influence of the air in a pipe on the reed by which it is set in vibration, causes the *quality* of the tone of a reed-pipe to depend materially on its figure. Thus it is found that a reed-pipe of the funnel-shaped form, fig. 24, composed of two cones, one more divergent than the other, set on the orifice, gives the clearest and most brilliant tone; but, on the other hand, if the upper cone be reversed, so as to contract the aperture, fig. 25, the Sound is stifled. But when two similar cones, placed base to base, are adapted to the aperture of a long conical pipe, as in fig. 26, the Sound acquires remarkable fullness and force. This belongs, however, to a most intricate part of the theory of Sound, the vibrations of masses of air in cavities of any form.

201. Influence of the reed on the quality of the Sound.

The quality of the tone produced by reed-pipes will also of course materially depend on the construction of the reed itself, and the substance of which it is composed. If the vibrating lamina be of metal, and at every vibration it strikes on a metallic orifice, these blows will be heard, and will give a harsh, rude, and screaming character to the Sound. If the edges of the aperture be covered with soft leather, this is much alleviated. But if, instead of *covering* the aperture by *striking on* it, the tongue is so constructed as merely to *obstruct* it by passing backwards and forwards *through* it at each oscillation, care being taken to make it *fit* without touching the edges of the aperture, these blows are avoided altogether; the tongue coming in contact with nothing but air during its whole motion. In consequence, its tone is remarkably soft and pure, and free from any harshness.

202. Grenié's reed. The Jew's harp.

The invention of this reed is ascribed by Biot to M. Grenié, who has taken out a patent for it; but, without erecting a prior claim on the part of Kratzenstein, we may bring forward a very familiar instrument, the Jew's-harp, as offering, at least, an apparent analogy with M. Grenié's reed. The construction of this instrument is so well known that there is no need to describe it; and though the theory of it be somewhat obscure, there can be little doubt that its action is that of a reed which calls into play the resonance of the cavity of the mouth, and sympathizes with it in its vibrations, at least in some of their modes. The Jew's-harp is an instrument much mistaken and unjustly contemned. Nothing can exceed the softness, sweetness, and delicacy of this instrument, when carefully constructed and well played;* as might be expected from a reed in which the tongue is perfectly at liberty. That the instrument itself vibrates in unison with the note it calls forth, is evident from the fact, that when merely held before the open mouth, or lightly retained between the lips, its Sound is feeble and scarce audible; but acquires a great accession of force when brought in contact with and firmly held between the teeth; the note is still further sustained and reinforced by directing a current of air forcibly through it. It is not here meant to say, that the great oscillations to and fro of the tongue are commanded by the resonance of the cavity, or are performed in the same time with its vibrations. On the contrary the spring is far too strong and large to admit of this. It is more probably by a series of subordinate vibrations going on in the tongue while oscillating, that the sympathy is established.

203. The German harmonica.

The instrument called the German harmonica is a reed, on M. Grenié's principle, consisting of nothing but a very thin lamina of brass, of the form of an oblong parallelogram fixed by one of its narrow ends in a frame of its own shape, but just so much larger as to allow of its free motion. This instrument vibrates by a blast urged through it yielding a clear musical tone of a very pleasing character and fixed pitch. If placed at the end of a pipe it performs the office of a reed, and its tone commands, or is commanded, by the pipe according to circumstances, as above explained.

204. Case where the pipe is commanded by the embouchure.

When the action of the embouchure of a pipe is so decided as to be incapable of being, to any sensible extent, commanded or influenced by the resonance of the pipe; as, for instance, when the column of air in a stopped pipe is set in vibration by a tuning-fork furnished with a disc, as described in Art. 119, the pipe will sound, and reinforce the Sound of the tuning-fork, but more and more feebly, as the pitch of the latter departs more from that of the pipe. The experiment is easily made by tuning the upper joint of a flute with the mouth-hole stopped exactly in unison with a fork, and then moving the piston of cork at the end of the pipe to and fro, or loading the fork with wax, so as to put it more or less out of tune. The fork and aerial column vibrate as a system, in which the former has so much the preponderance as to command the latter completely.

205.

We may here notice a very remarkable experiment, which we do not remember to have seen elsewhere

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* As we have heard it done by M. Eulenstein.

Singular experiment: a double Sound yielded by one pipe. described, and which shows to what an extent the principle of the *superposition* of vibrating motions and the simultaneous coincidence of different modes of vibration in the same vibrating body, must be admitted in Acoustics. If, instead of one, two such disked tuning-forks be held over the mouth of a pipe side by side, both nearly in unison with the pipe, but purposely tuned out of unison with each other, by an interval so small (see Index, *Musical Intervals*) as to produce strong beats, (see Index, *Beats*,) *both* Sounds at once will be reinforced by the pipe, and the beats will be heard with the same degree of distinctness as if two pipes, each in unison with one of the forks, were sounding side by side. The same column of air, then, at the same time, is vibrating as a part of two distinct systems, and each series of vibrations, however near coincidence they may be brought, continues perfectly distinct and absolutely free from any mutual influence. To those who have not tried the experiment, the fact of a pipe actually out of tune with itself, and yielding two notes in irreconcilable discord with one another, yet both equally clear and loud, will, at first sight, appear not a little extraordinary.

206. Vox humana organ-pipe. Fig. 27. One of the most singular species of pipe is that employed in the organ to imitate the human voice. It is composed of a very short conical pipe, the base upwards surmounted by a short cylinder, and the pitch is regulated entirely by the reed. (See fig. 27.) There is a circular operculum which half closes the open end of the cylinder, to imitate the lips, the reed performing the part of the larynx, and the pipe itself, of the cavity of the throat and mouth. (See Index, *Voice*.) This pipe, when well executed, imitates the human voice extremely well; but with a peculiar nasal twang, and somewhat of a screaming tone.

207. Chimney-pipes. Fig. 28. Chimney-pipes are those which are closed at the upper end by a cover, through the centre of which a pipe of smaller diameter is passed, as a continuation of the lower one. (Fig. 28.) Their Sound is intermediate between those of open and stopped pipes of the same length. Bernouilli (*Mém. Acad. Par.* 1762) has investigated the laws of their vibrations. (See also Biot, *Traité de Phys.* ii. p. 153.) If we call L and l the lengths of the greater and smaller pipes respectively, and λ that of a pipe closed at one end capable of yielding the same fundamental note, $n : 1$, the ratio of their diameters, Bernouilli finds the following equation for determining λ,

$$\tan\left(\frac{\pi}{2} \cdot \frac{L}{\lambda}\right) \times \tan\left(\frac{\pi}{2} \cdot \frac{l}{\lambda}\right) = \frac{1}{n^2}.$$

This equation holds good when the lower end of the great pipe is closed; if it be open, the equation is

$$\tan\left(\frac{\pi}{2} \cdot \frac{L-\lambda}{2\lambda}\right) . \tan\left(\frac{\pi}{2} \cdot \frac{l}{\lambda}\right) = \frac{1}{n}.$$

§ IV. *Of Musical Intervals, of Harmony, and Temperament.*

208. Unisons. Our appreciation of the *pitch* of a Musical Sound depends, as we have seen, entirely on the number of its vibrations performed in a given time. Two Sounds whose vibrations are performed with equal rapidity, whatever be their difference in quality or intensity, affect the ear with a sentiment of accordance which we term a *unison*, and which irresistibly impresses on us the conviction of a perfect analogy, or similarity between them, which we express by saying that their *pitch* is the same, or that they sound the same *note*. In fact, their impulses on the air, and on the ear, through its medium, occurring with equal frequency, blend, and form a compound impulse, differing in quality and intensity from either of its constituents, but not in the frequency of its recurrence; and, therefore, the ear will judge of it as of a single note of intermediate quality.

209. Musical concords and discords. But when two notes not in unison are sounded at once, the ear distinctly perceives both, and (at least with practice, and some ears more readily than others) can separate them, in idea, and attend to one without the other. But besides this, it receives an impression from them jointly, which it does not acquire when sounded singly, even in close succession, an impression of concord, or dissonance, as the case may be; and is irresistibly led to regard some combinations as peculiarly agreeable and satisfactory, and others as harsh and grating. Now it is invariably found that the former are those, and those only, in which the vibrations of the individual notes are in some very simple numerical proportion to each other, as 1 to 2, 1 to 3, 1 to 4, 2 to 3, &c., and that the concord is more satisfactory and more pleasing, the lower the terms of the proportion are, and the less they differ from each other. While, on the other hand, such notes as vibrate in times bearing no simple numerical ratio to each other, or in which the times of the ratio are considerable, as 8 : 15, for example, when heard together produce a sense of discord, and are extremely unpleasant. This simple remark is the natural foundation of all harmony.

210. The octave. Fig. 29. Next to a *unison*, in which the vibrations of the two notes are in the ratio of 1 : 1, the most satisfactory concord is the *octave*, where the vibrations are as 1 : 2, or one note performs two vibrations to each single one of the other. The *octave* approaches in its character to a unison, and indeed two notes so related when played together can hardly be separated in idea; and when singly, appear rather as the same note differently modified, than as independent Sounds. The reason of this will be evident on inspecting fig. 29, where the dots in the upper line represent the periodically recurring impulses on the ear produced by the vibrations of the acuter note, while those in the lower represent the same impulses as produced by those of the graver; as the ear receives these all in the order they are placed, it will be the same thing as if they were produced by two Sounds both of the graver pitch, but one of a different intensity and quality from the other; the one having its impulses (represented by :) the sum of two separate impulses of the octave Sounds; the other consisting of the alternate impulses (.) of the acuter only.

211 In like manner the *octave* of the *octave*, or the *fifteenth*, as it is called in Music, which consists of notes whose

The double octave, or fifteenth, &c.

vibrations are as 1 : 4, is a very agreeable and perfect concord; as are, indeed, all the scale of octaves 1 : 8, 1 : 16, &c. they all partake of the peculiar character of the octave, a sense of perfect adjustment or identity.

212. The twelfth. Fig. 30. The fifth. Fig. 31.

The next in order is the combinations 1 : 3, where the vibrations of the graver note are trisected by those of the acuter, as in fig. 30, which gives a concord called the twelfth, a very agreeable one. In this, if we substitute for the note 1 its octave 2, we shall have the concord whose vibrations are in the ratio of 2 : 3; or, as we shall call it for brevity, the concord 2 : 3, whose pulsations are represented in fig. 31. This concord is termed the *fifth*, and is a remarkably perfect and agreeable one, even more so than the twelfth, which although simpler in a numerical estimate, yet from the greater interval between its component notes allows them to be more readily distinguished, while the notes of the fifth blend much more perfectly.

213. The fourth. Fig. 32.

If, instead of substituting for 1 its octave 2, we substitute its double octave 4, we get the concord 4 : 3, or the *fourth*, which may be regarded as a sort of complement of the *fifth*, and is also very agreeable.

214. The major third. Fig. 33. The minor sixth.

The concords 1 : 5, 2 : 5, and 4 : 5, especially the latter, in which the tones approach pretty near to each other, are all remarkably agreeable. The last is called a *major third*, and the two former are regarded rather as varieties of it than as independent concords. The concord 8 : 5 (which is its complement in the same sense as 4 : 3 the fourth is to 2 : 3 the fifth) is called the *minor sixth*, and is almost equally agreeable with the major third, to which it is related.

215. The minor third and major sixth.

The concord 3 : 5 is called the *major sixth*, and, as well as its complement 6 : 5, or the *minor third*, though pleasing, is decidedly less satisfactory than the foregoing; and, as we see by casting our eyes on the figure, the periods of recurrence of their combined pulses in the same order is longer and more complex.

216. Discords and their resolution.

217. Example in the resolution of the discord of the flat seventh.

Higher primes than 5 enter into no harmonic ratios. Such combinations, for instance, as 1 : 7, 5 : 7, or 6 : 7, are altogether discordant. The same may be said of the more complicated combinations of the lower primes 1, 2, 3, 5. The ear will not endure them, and cannot rest upon them. When sounded, a sense of craving for a change is produced, and this is not satisfied but by changing one or both of the notes so as to fall as easily as the case will permit into some one of the concords above enumerated. This is called the resolution of a discord; and such is the constitution of our minds in this respect, that a concord agreeable in itself is rendered doubly so by being thus approached through a discord. For example, let us take the ratio 5 : 9, which is called a *flat seventh*, a combination decidedly discordant. If we multiply the terms of this ratio by 5, we get 25 : 45. A small change in one of the notes will reduce this to 27 : 45, or 3 : 5, a major sixth—an agreeable concord. Now this will be done, if, retaining the lower note 5 or 25, we change the upper from 45 to $45 \times \frac{25}{27}$; that is to say, to a note whose vibrations are to its own as 25 : 27. This ratio corresponds to a musical interval called a *semitone*. Hence the discord in question will be satisfactorily resolved by holding on its lower note, and making its upper one *descend a semitone*.

218. On the proper alternation of concords and discords the whole of musical composition depends, but though the principle above stated must be satisfied in the resolution of every discord, there are other rules to be attended to by which our choice is limited to some modes rather than others; for example, in the foregoing instance it is the upper note which must descend a semitone. The ascent of the lower by the same interval, which would equally change the ratio as above indicated, would offend against other precepts with which we have here nothing to do.

219. Musical intervals depend on ratios of vibrations, not on their absolute number.

The *interval*, as it is called in Music, between the two notes of which any simple concord or discord consists, depends not on the absolute number of vibrations which either makes in a given time, but on their relative proportion. For it is no matter how slowly, or how rapidly, the vibrations take place, provided the order in which their impulses reach the ear be the same. Hence, if the vibrations 4 and 5 produce on the ear the agreeable effect of a major third; two notes, each an octave higher, or having their vibrations respectively 8 and 10; or in general any two having their vibrations in this ratio, will produce the same effect. This is a matter of experience, but the inspection of the figures representing the order of succession of the individual vibrations enables us to understand its reason.

220. Completion of the scale by the second and seventh.

If we take any note for a fundamental Sound, and tune a string or a pipe so as to vibrate with the degree of rapidity corresponding to that Sound, and represent by unity the number of vibrations it makes per second; and if we also tune other strings to make in the same time respectively the numbers of vibrations represented by $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, 2; and then sound all these strings in succession, beginning with the fundamental note, we shall perceive that two of the sequences, the first and last, are much wider than the rest, and would admit the interpolation of a note between each. But it is no longer possible to choose for these interpolated notes such as will make concordant intervals with any of the rest, or their octaves. But in order to obtain as many concords as possible in the scale, so as to produce the most harmonious music, they are made to harmonize with that note which bears the nearest relation to the fundamental one, (for its octave is regarded as a mere repetition of itself,) *i. e.* the fifth. The vibrations of a note a fifth higher than the fifth are represented by $\left(\frac{3}{2}\right)^2$, or $\frac{9}{4}$; and as this is greater than 2, it lies beyond the octave. We must, therefore, tune our interpolated string an octave lower, or to the vibration $\frac{9}{8}$, and thus we get the *second*. Again, if we tune another to the vibration $\frac{15}{8}$, or $\frac{5}{4} \times \frac{3}{2}$, it will form, with the fifth of the fundamental note $\left(\frac{3}{2}\right)$, a major third—the next most harmonious interval on the scale. The note thus interpolated is the *seventh*.

The second.

221. The interpolated scale, with the vibrations of its respective notes, will stand thus:

Signs	(1),	(2),	(3),	(4),	(5),	(6),	(7),	(8).
Names of intervals	1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.
Ratios of vibration...........	1,	$\frac{9}{8}$,	$\frac{5}{4}$,	$\frac{4}{3}$,	$\frac{3}{2}$,	$\frac{5}{3}$,	$\frac{15}{8}$,	2.

or multiplying all by 24, to avoid fractions,

24, 27, 30, 32, 36, 40, 45, 48.

Diatonic scale. This is called the natural, or diatonic scale; when all its notes are sounded in succession, whether upwards or downwards, the effect is universally acknowledged to be pleasing. The ear rests with perfect satisfaction on the fundamental note, and the intervals succeed each other gracefully, with sufficient variety to avoid monotony. Accordingly all ages and nations have agreed in adopting this scale as the foundation of their music.

222. Continuation of the scale upwards and downwards. Limits of audibility. Sounds inaudible to certain ears. This scale consists of seven distinct notes, for the eighth being the octave of the first is regarded as a mere repetition of it. And if we add to it on both sides the octaves of all its tones above and below, and again the octaves of these, and so on, we may continue it indefinitely upwards and downwards. Not that the ear will follow these additional tones, to an unlimited extent. When the vibrations are less numerous than about 16 per second, the ear loses the impression of a continued Sound; and perceives, first, a fluttering noise, then a quick rattle, then a succession of distinct Sounds capable of being counted. On the other hand, when the frequency of the vibrations exceeds a certain limit all sense of *pitch* is lost; a shrill squeak, or chirp, only is heard; and, what is very remarkable, many individuals, otherwise no way inclined to deafness, are altogether insensible to very acute Sounds, even such as painfully affect others. This singular observation is due to Dr. Wollaston. (See his Paper on Sounds inaudible to certain ears, *Phil. Trans.* 1820.) Nothing can be more surprising than to see two persons, neither of them deaf, the one complaining of the penetrating shrillness of a Sound, while the other maintains there is no Sound at all. Thus while one person mentioned by Dr. Wollaston could but just hear a note four octaves above the middle E of the piano-forte, others have a distinct perception of Sounds full two octaves higher. The chirp of the Sparrow is about the former limit; the cry of the Bat about one octave above it; and that of some insects, probably, more than another octave. Dr. Wollaston's sense of hearing terminated at six octaves. The whole range of human hearing comprised between the lowest notes of the organ and the highest known cry of insects, seems to include about nine octaves.

223. Remark. Feebleness of very acute Sounds. It is probable, however, that it is not alone the *frequency* of the vibrations which renders shrill Sounds inaudible. There is no reason why an impulse, if strong enough *singly* to affect the ear, should lose its effect if repeated many thousand times in a second. On the contrary such repetition would render the noise intolerable. But this is not the case with musical Sounds; their individual impulses would, probably, be quite inaudible singly, and only impress by repetition. Now, as vibrating bodies have only a certain degree of elasticity, extreme swiftness of vibration can only take place when their dimensions are very minute, and consequently the excursions of their molecules from rest, and their absolute velocities, excessively minute also. Thus in proportion as Sounds are more acute their *intensity* (which depends wholly on the extent and force of their vibrations) diminishes. No doubt, if by any mechanism a hundred thousand hard blows per second could be regularly struck by a hammer on an anvil, at precisely equal intervals, they would be *heard* as a most deafening shriek; but in natural Sounds the impulses lose in intensity more than they gain in number, and thus the Sound grows feebler and feebler till it ceases to be heard.

224. Possible limits of the sense of hearing in different animals. "As there is nothing in the nature of the atmosphere (remarks Dr. Wollaston) to prevent the existence of vibrations incomparably more frequent than any of which we are conscious, we may imagine that animals like the Grylli, whose powers appear to commence nearly where ours terminate, may have the faculty of hearing still sharper Sounds, which we do not know to exist; and that there may be other insects hearing nothing in common with us, but endued with a power of exciting, and a sense which perceives vibrations of the same nature indeed as those which constitute our ordinary Sounds, but so remote that the animals who perceive them may be said to possess another sense agreeing with our own solely in the medium by which it is excited." The same may, no doubt, be true of aquatic animals. The shrimp and the whale may have no Sound in common.

225. Key-note of a piece of music. Its analysis into chords. By the aid of the ascending and descending series of Sounds in the natural scale thus obtained, pieces of music perfectly pleasing, both in point of harmony and melody, may be played; and they are said to be in the *key* of that which is assumed as the fundamental note of the scale, or whose vibrations are represented by 1. If such a piece be analyzed, it will be found to consist entirely, or chiefly, of triple and quadruple combinations, or chords, such as the following:

226. The fundamental or common chord. 1. The common, or fundamental chord, or chord of the *tonic*, or the 1st, 3d, and 5th, (1, 3, 5,) or the 3d, 5th, and octave (3, 5, 8) sounded together. This is the most harmonious and satisfactory *chord* in music, and when sounded the ear is satisfied, and requires nothing further. It is, therefore, more frequently heard than any other; and its continual recurrence in a piece of music determines the *key* it is played in.

227. Chord of the dominant. 2. The chord of the *dominant*. The fifth of the key-note is called, by reason of its near relation to the fundamental note, the dominant. The chord in question is the common chord of the dominant, or the notes (2, 5, and 7) sounded together.

228. Chord of the subdominant. 3. The chord of the *subdominant*, or the note 4, consisting of the notes 1, 4, 6, being the common chord of 4 as a fundamental note.

229 4. The false close, or the combination (1, 3, 6) or (3, 6, 8) which is, in fact, the common chord of the note 6, only with a minor third (6, 8) instead of a major. The term *false close* arises from this, that a piece of music, frequently before its final termination, (which is always on the fundamental chord,) comes to a momentary close

on this chord, which pleases only for a short time, but requires the strain to be taken up again and closed as usual to give full satisfaction.

The false close.

230. Chord (or discord) of the seventh.

5. The discord of the 7th, or (2, 4, 5, 7.) It consists of four notes; and is, in fact, the common chord of the dominant, with the note immediately below it, or the seventh *in order* above it. The interval, however, between the notes (4) and (5), or between (5) and the octave of (4) next above it, is represented by the ratio

$$\frac{2 \times 4}{3} \div \frac{3}{2} = \frac{16}{9},$$

or (taking 24 as the number of vibrations in a unit of time corresponding to the note (1)) $= 42\frac{2}{3}$. This interval, then, is less than the seventh of the diatonic scale, and is about half-way intermediate between the sixth and seventh of that scale. It is, therefore, called the flat seventh. (See Arts. 231 and 232.) This discord resolves itself into the chord (3, 5, 8;) and unless that combination, or one equivalent to it, follows, the ear is not satisfied.* The notes (4) and (5) are the essential ones of this discord, and the others are regarded as accompaniments. If played together, the ear requires that in the next chord 4 should descend or be succeeded by (3,) while the note 7 is required to rise or be succeeded by (8.)

231. Modulation.

With these chords and a few others, such as the chord of the 9th, whose essential notes are 1 and 2, or 1 and 9, may a great variety of music be played, but it would be found monotonous. The ear requires, in a long piece, a variety of *key*. The fundamental note occurs so often that it seems to pervade the whole of the composition, and must therefore be changed. But this change of key, which is called *modulation*, is not possible without introducing other notes than those already enumerated. It is true the chord (2, 5, 7) is the perfect fundamental chord in the key of (5;) but the other chords in that key corresponding to those already enumerated cannot be formed, with the exception of its sub-dominant, which is, in fact, the common chord of 1. Take, for instance, its dominant. This would be formed, if it could be formed at all, of the notes (2, 4, 6) or (4, 6, 9.) But if we come to analyze the intervals of these notes, we find that

Necessity of introducing intermediate notes.

$$\frac{(4)}{(2)} = \frac{32}{27}; \quad \frac{(6)}{(2)} = \frac{40}{27}.$$

Now these differ from the ratios $\frac{5}{4}$ and $\frac{3}{2}$ which exist between the notes (3, 1) and (5, 1) of the perfect common chord. Consequently, if we would play equally well in tune in the key (5) we must introduce these new ratios; and, in fact, we ought to have for that purpose notes corresponding to all the ratios

$$\frac{3}{2} \times \frac{9}{8}, \quad \frac{3}{2} \times \frac{5}{4}, \quad \frac{3}{2} \times \frac{4}{3}, \text{ \&c.}$$

and similarly for every other key we might choose to play in. But this would require an enormous number of notes, and would render the generality of musical instruments too complicated. It becomes necessary, then, to consider how the number may be reduced, and what are the fewest notes that will answer.

232. Exemplified by a numerical example.

Let us take for example, as above, the dominant of the note (5.) The number of its vibrations is $36 \times \frac{3}{2}$, or 54, the half of which (because it surpasses the octave of 1) is 27. This is correctly the number corresponding to (2.) Now, taking this for a key-note, the major third of (2) has $27 \times \frac{5}{4} = 34\frac{1}{4}$ for the number of its vibrations in a unit of time. Now in the scale as it stands we have 32 and 36, so that the note in question is almost just half-way between them, and must therefore be interpolated. It will stand between (4) and (5) on the scale, and is denoted in Music by the sign ♯ *sharp*, or ♭ *flat*; thus it is written either as (4) *sharp*, (4)♯, or as (5) *flat*, (5)♭. With regard to the fifth of the new fundamental note (2) its representative number is

Flats and sharps.

$$27 \times \frac{3}{2} = \frac{81}{2} = 40\frac{1}{2}.$$

This comes so near 40, that the ear hardly perceives the difference; and though a small error of one vibration in 80 is introduced by using the note (6) as the dominant of (2,) yet it is not fatal to harmony; and there is no necessity for encumbering ourselves with new names of notes, and additional pipes or strings to our instruments for its sake. In practice these errors are modified and subdued by what is called *temperament*, of which this is the origin, and of which more presently.

Introduction of imperfect harmony.

233. The comma.

The interval $\frac{81}{80}$ being the difference of two notes, one of which is the octave of the perfect sixth of the fundamental note, and the other arises by reckoning upwards three perfect fifths from the same origin, is called a comma. The former note is represented by

$$2 \times \frac{5}{3} = \frac{10}{3}, \quad \text{the latter by} \left(\frac{3}{2}\right)^3 = \frac{27}{8}, \quad \text{and } \frac{27}{8} \div \frac{10}{3} = \frac{81}{80}.$$

234.

In like manner, if we would choose any other note for the fundamental one, similar changes will be required, and no two keys will agree in giving identically the same scale. All, however, will be nearly satisfied by the interpolation of a new note half-way between each of the larger intervals of the scale, thus

The chromatic scale.

$$1,\ \left.\begin{matrix}1\sharp\\ \text{or}\\ 2\flat\end{matrix}\right\},\ 2,\ \left.\begin{matrix}2\sharp\\ \text{or}\\ 3\flat\end{matrix}\right\},\ 3,\ 4,\ \left.\begin{matrix}4\sharp\\ \text{or}\\ 5\flat\end{matrix}\right\},\ 5,\ \left.\begin{matrix}5\sharp\\ \text{or}\\ 6\flat\end{matrix}\right\},\ 6,\ \left.\begin{matrix}6\sharp\\ \text{or}\\ 7\flat\end{matrix}\right\},\ 7,\ 8;$$

and the scale so interpolated is called the chromatic scale.

235. Of temperament. Musicians have long been at issue on the most advantageous method of executing this interpolation. If, indeed, it were intended to give such a preference to the natural scale 1, 2, 3, 4, &c. as to make *it* perfect, to the sacrifice of all the other keys, there would be little difficulty, as a mere bisection of the intervals would, probably, answer every practical purpose: thus $1\sharp$ or $2\flat$ might be represented by $\sqrt{1 \times \frac{9}{8}}$; $2\sharp = 3\flat$ by $\sqrt{\frac{9}{8} \times \frac{5}{4}}$, and so on; but as in practice no preference is given to this particular key, (which is denoted in Music by the letter C,) but, on the contrary, variety is purposely studied, it is found necessary to depart from the pure and perfect diatonic scale, even in tuning the natural notes; and to do so with the least offence to the ear is the object of a perfect system of temperament.* If the ear absolutely required perfect concords there could be no music, or but a very limited and monotonous one. But this is not the case. Perfect harmony is never heard, and if heard would probably be little valued, except by the most refined ears; and it is this fortunate circumstance which renders musical composition, in the exquisite and complicated state in which it at present exists, possible.

236. Beats. In order to judge of the limits, however, to which the ear will bear a deviation from exact consonance of musical vibrations, we must first see what takes place when two notes nearly, but not quite, in unison or concord are sounded together. Conceive two strings exactly equal and similar, and equally drawn out from the straight line, to be let go at the same instant; and suppose one to make 100 vibrations per second, the other 101; let them be placed side by side, and at the same distance from the ear. Their first vibrations will conspire in producing a Sound-wave of double force, and the impression on the ear will be double. But at the 50th vibration one has gained half a vibration on the other, so that the motions of the aerial particles, in virtue of the two coexistent waves emanating from either string, are now not in the same but in opposite directions; and the two waves being by supposition of equal intensity, they will instead of conspiring exactly destroy each other, and this will be very nearly the case for several vibrations on either side of the 50th. Consequently, in approaching the 50th vibration, the joint Sound will be enfeebled; there will be a moment of perfect silence, and then the Sound will again increase till the 100th; when the one string having gained a whole vibration on the other, the motions of the particles of air in the two waves will again completely conspire, and the Sound will attain its maximum. The effect on the ear will therefore be that of an intermitting Sound alternately loud and faint. These alternate reinforcements and subsidences of the Sound are called *beats.* The nearer the Sounds of the strings approach to exact unison, the longer is the interval between the beats. If we call n the number of vibrations in which one string gains or loses exactly one vibration on the other, and m the number of vibrations per second made by the quicker, $\frac{n}{m}$ will be the interval between two consecutive beats. When the unison is complete, no beats are heard. On the other hand, when it is very defective they have the effect of a rattle of a very unpleasant kind. The complete destruction of the beats affords the best means of attaining by trial a perfect harmony.

237. Beats heard with all imperfect concords. Beats will likewise be heard when other concords, as fifths, are imperfectly adjusted. Suppose one string to make 201 vibrations, while the other makes 300; then, at and about the 100th of one, and the 150th of the other, the former will have gained half a vibration, and those vibrations of the one which fall exactly on those of the other, (see fig. 31,) being performed with contrary motions will destroy each other; those which fall intermediate only partially. The beats then will be heard, but with less distinctness than in the case of unisons.

238. Resultant Sounds. This seems the proper place to notice an effect which takes place in perfect concords, and only in those which are very perfect, *viz.* the production of a grave Sound by the mere concurrence of two acute ones. If we examine the figure 212, which represents the succession of vibrations in a perfect fifth, we shall see that every third of the one coincides exactly with every second vibration of the other. These coincidences (so delicate is the ear) are remarked by it, and a Sound is heard, besides the two actually sounded, of a pitch determined only by the frequency of the precise coincidences; that is, in this case, a precise octave below the lowest tone of the concord.

239. General determination of the resultant tone. In general, if one note makes m vibrations and the other n, while another, of which they may both be regarded as harmonics, makes one, that one will be the resultant tone, provided m and n be prime to each other; so that the only difficulty in determining the resultant of two notes, is to determine of what they are both harmonics. This will be done by reducing m and n, if fractions, to a common denominator $\frac{m'}{N}$ and $\frac{n'}{N}$; then, if m' and n' have no common factor, $\frac{1}{N}$ will represent the fundamental tone. If, then, m and n be integers, and without any common factor, the resultant will be represented by 1.

240. One note heard from the concourse of a great many.

Hence follows a very curious fact, *viz.* that if several strings, or pipes, be tuned *exactly* to be harmonics of one of them, or to have their vibrations in the ratios 1, 2, 3, 4, 5, &c., then if they be all, or any number of them, from the first onward, sounded together, there will be heard but one note, *viz.* the fundamental note. For they are all harmonics of the first note 1; and, moreover, if we combine them all two and two, we shall find comparatively but few which will give other resultants, so that these will be lost, as well as the individual Sounds of the strings, all but the first, in the united effect of all the resultant unit Sounds. But to produce this effect, the strings, or pipes, must be very perfectly tuned to the strict harmonics. The effect can never take place by touching the keys of a piano-forte corresponding to the harmonic notes, because they are always of necessity tempered.

241. The scale of equal intervals, or iso-harmonic scale.

To return to our temperament. If we count the semitones in the chromatic scale between (1) and (8) we shall find the number of such intervals 12. If, then, we would have a scale exactly similar to itself in all parts, and which should admit of our playing equally perfectly in every key, we have only to compute the values of the fractions

$$1 = 2^0,\ 2^{\frac{1}{12}},\ 2^{\frac{2}{12}},\ 2^{\frac{3}{12}} \ldots\ldots\ 2^{\frac{11}{12}},\ 2,$$

which may readily be done by logarithms, and we shall find the ratios of the vibrations which will give what may be termed the scale of equal intervals.

242. System of equal temparament.

If we examine the chromatic scale, and consider it as approximatively composed of equal, or nearly equal, intervals called semitones, the following will be the number of semitones in each interval:

In the semitone	1	In the major fifth or fifth	7
——— second or tone	2	——— minor sixth	8
——— minor third	3	——— major sixth	9
——— major third	4	——— flat seventh	10
——— minor fourth or fourth	5	——— seventh	11
——— major fourth or minor fifth	6	——— octave	12

If then we reckon upwards from the note (1) by fifths, *viz.* from (1) to (5), from (5) to (9), (or, which comes to the same, descending an octave, to (2),) from (2) to (6), from (6) to (10), that is to (10 − 7), or (3), and so on, we shall find that after taking twelve such steps as these we shall have fallen upon every note in the scale, and come back to the fundamental note or its octave. But, since no power of 2 is exactly the same with any power of $\frac{3}{2}$, it is evident that no series of steps by *perfect* fifths can ever bring us to any one of the octaves of the fundamental note. Were the chromatic scale perfect, twelve fifths should exactly equal seven octaves, and three major thirds should precisely make one octave. Neither of these, however, can be true of *perfect fifths* or *thirds*, for $\left(\frac{3}{2}\right)^{12} = 129{\cdot}74$, and $2^7 = 128$, giving a difference of nearly one vibration in 64 and $\left(\frac{5}{4}\right)^3 = 1{\cdot}953$ instead of 2. Thus, if we reckon upwards by perfect fifths, we surpass the octaves; if by thirds, we fall continually below them. In this dilemma it has been proposed to diminish all the fifths equally, making a fifth instead of $\frac{3}{2}$, to be equal to $2^{\frac{7}{12}}$; and tuning regularly from the note (1) upwards by such fifths and from the notes so tuned downwards by perfect octaves. This constitutes what has been called the system of equal temperament.

243. Defect of this system.

It is, evident that in this system the notes will all of necessity be represented by powers of $2^{\frac{1}{12}}$; and that therefore the scale resulting from this system is identical with that of equal intervals, or the iso-harmonic scale described in the last article. Theoretically speaking, it is the simplest that could be devised; and, practically, (though fastidious ears may profess to be offended by it,) it must produce no contemptible harmony. It has, however, one radical fault, it gives all the keys one *character*. In any other system of temperament some intervals, though of the same denomination, must differ by a minute quantity from each other; and this difference falling in one part of the scale in one key, in another in another, gives a peculiarity of quality to each key, which the ear seizes and enjoys extremely. This fact, in which, we believe, all practical musicians will agree, is alone sufficient to prove, that *perfect* harmony is not necessary for the full enjoyment of music. Most practical musicians seem to have no fixed or certain system of temperament; at least very few of them when questioned appear to have any distinct ideas on the subject.

244. Occasional temperament.

It is a mistake to suppose, as some have done, that temperament applies only to instruments with keys and fixed tones. Singers, violin players, and all others who can pass through every gradation of tone, must all temper, or they could never keep in tune with each other or with themselves. Any one who should keep on ascending by perfect fifths, and descending by octaves or thirds, would soon find his fundamental pitch grow sharper and sharper till he could at last neither sing nor play; and two violin players accompanying each other, and arriving at the same note by different intervals, would find a continual want of agreement.

245. Musical intervals represented by logarithms.

Musical intervals may be numerically represented by the logarithms of the fractions expressing the ratios of the vibrations of the notes between which the intervals are comprised; for the interval depending only on this ratio, and the sum of any two intervals corresponding to the product of their respective ratios, the logarithms of the latter are the proper measures of the magnitudes of the former. Thus an octave corresponds to a ratio of 2 : 1 of the vibrations of its extreme Sounds; two octaves to the ratio 4 : 1 or 2^2 : 1, three to 8 : 1 or 2^3 : 1, and so on; so that log. 2, 2. log. 2, 3. log. 2, &c. or any numbers in that proportion, are proper numerical representatives of these intervals. The intervals of the diatonic scale will, therefore, be represented logarithmically as follows·

	Interval.	Ratio.	Logarithm.	Approx.	Differences.
(1) to (1)	0	1	000000	0	
(1) to (2)	Major tone = τ.	$\frac{9}{8}$	005115	51	51 = τ
(1) to (3)	Major 3d = III	$\frac{5}{4}$	009691	97	46 = *t*
(1) to (4)	Minor 4th = IV.	$\frac{4}{3}$	012494	125	28 = θ
(1) to (5)	Major 5th = V.	$\frac{3}{2}$	017609	176	51 = τ
(1) to (6)	Major 6th = VI.	$\frac{5}{3}$	022185	222	46 = *t*
(1) to (7)	Major 7th = VII.	$\frac{15}{8}$	027300	273	51 = τ
(1) to (8)	Octave = VIII.	2	030103	301	28 = θ

The approximate values of the intervals being all true to a 500th of a tone, an interval far too minute for the nicest ear to appreciate, may be used in all musical calculations where high multiples of them are not taken.

246. **Sequence of intervals in the diatonic scale.** It will be observed that the diatonic scale so constructed, consists of three different intervals between consecutive notes. Thus, the interval from (1) to (2) is 51 parts of a scale on which the octave measures 301. This is called a *major tone*, τ, and the same interval occurs again between (4) and (5), and between (6) and (7), as will appear by referring to the column of differences. Again, the interval from (2) to (3) is 46 such parts only, and this, which occurs again between (5) and (6), is called a *minor tone*, (*t*). Lastly, the interval between (3) and (4) and between (7) and (8) is 28 such parts, and is called (but more improperly) a semitone, (θ), being in fact much more than the half of either a major or a minor tone. The term *limma*, which has been used by some authors, is much preferable.

247. **Enharmonic diesis.** This is the origin of what is called the *enharmonic diesis*, and of the distinction existing between the sharp of one note and the flat of that next above it; a distinction essential to perfect harmony, but which cannot be maintained in practice, except in organs and complicated instruments, which admit a great variety of keys and pedals, or in stringed instruments or the voice, where all gradations of tone can be produced, and then only when used without a fixed accompaniment. To explain this distinction, suppose, in the course of a piece of music, commenced in the key of (1), we should *modulate*, as it is called, into the key of (4), its sub-dominant; that is, change our key, and adopt a new scale, having (4) for its fundamental tone. To make the new scale perfect, the intervals should be the same, and succeed each other in the same order as in the original key (1). That is, setting out from (4) we ought to have for our sequence of intervals $\tau\, t\, \theta\, \tau\, t\, \tau\, \theta$. Now, this sequence does not take place in the unaltered scale of (1), when we set out from any note but (1), and if we prolong it backward to (4), they will stand thus,

$$\begin{array}{c}(4)\quad\;(5)\quad\;(6)\quad\;(7)\quad\;(1)\quad\;(2)\quad\;(3)\quad\;(4)\\ \underbrace{\big|\;\;\tau\;\;\big|\;\;t\;\;\big|}\underbrace{\;\;\tau\;\;\big|\;\;\theta\;\;\big|}\underbrace{\;\;\tau\;\;\big|\;\;t\;\;\big|\;\;\theta\;\;\big|}\end{array}$$

whereas they ought to stand thus,

$$\begin{array}{c}(4)\quad\;(5)\quad\;(6)\quad\;(7)\quad\;(1)\quad\;(2)\quad\;(3)\quad\;(4)\ \text{\&c.}\\ \underbrace{\big|\;\;\tau\;\;\big|\;\;t\;\;\big|}\underbrace{\;\;\theta\;\;\big|\;\;\tau\;\;\big|}\underbrace{\;\;t\;\;\big|\;\;\tau\;\;\big|\;\;\theta\;\;\big|}\ \text{\&c.}\end{array}$$

The first two intervals are the same in both. The two next will also agree if we *flatten* the note (7), so as to make $(7)\flat - (6) = \theta$ and $(1) - (7)\flat = \tau$, which leaves the interval $(1) - (6)$ the same as before, *viz.* $\tau + \theta$, or a perfect minor third. The quantity by which (7) must be flattened for this purpose, or $(7) - (7)\flat$, is equal to $\tau - \theta = 51 - 28 = 23$, and this is the amount by which *in this case* a note differs from its flat. As to the remaining three intervals, the difference between τ and *t* being small, amounting only to 5, (which is the logarithmic representative of the ratio $\frac{81}{80}$, or *a comma*,) the sequence $t\, \tau\, \theta$ is hardly distinguishable from $\tau\, t\, \theta$, and if the note (2) be *tempered flat* by an interval $= \frac{\tau - t}{2}$, or half a comma, this sequence will in both cases be the same, and our two scales of (1) and (4) will be rendered as perfect as the nature of the case will permit, by the interpolation of only one new note. But, on the other hand, suppose we would modulate into the key (7). In this case the scales will stand thus:

$$\begin{array}{ccccccccccccccccl}(7) & & (1) & & (2) & & (3) & & (4) & & (5) & & (6) & & (7) & \\ \big| & \theta & \big| & \tau & \big| & t & \big| & \theta & \big| & \tau & \big| & t & \big| & \tau & \big| & \text{Perfect scale of (1).}\\ \big| & \tau & \big| & t & \big| & \theta & \big| & \tau & \big| & t & \big| & \tau & \big| & \theta & \big| & \text{Perfect scale of (7).}\\ (7) & & (1)\sharp & & (2)\sharp & & (3) & & (4)\sharp & & (5)\sharp & & (6)\sharp & & (7) & \end{array}$$

This change will require the interpolation of no less than five new notes; the notes (7) and (3) being the only ones that remain unchanged. But to confine ourselves to the change from (6) to (6)♯, we have $(7) - (6) = \tau$ and $(7) - (6)\sharp = \theta$. Consequently $(6)\sharp - (6) = \tau - \theta = 23 = (7) - (7)\flat$, as before determined. But since the whole interval between (6) and (7), or $(7) - (6)$, which is $= \tau = 51$, is more than double of this quantity, the flattened note (7)♭ will lie nearer to the higher note (7), and the sharpened one (6)♯ nearer to the lower one (6) than a note arbitrarily interpolated half way between them, to answer both purposes approximately, would do, and thus a gap, or, as it is termed, a *diesis*, would be left between (6)♯ and (7)♭.

The diesis in this case amounts only to a comma (= 5), or the tenth part of a *major tone*, (τ) (= 51), is

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other cases it would be greater. But in all cases the interval between any note and *its sharp* is considered to be equal to that between the same note and *its flat*. Assuming this as a principle, a variety of systems of temperament have been devised for producing the best harmony by a system of 21 fixed Sounds, *viz.* each note of the seven in the scale, with its sharp and flat, (regarded as different). 248. Systems of 21 fixed Sounds in the octave.

249. Huygens's system. The first and most celebrated is that of Huygens. He supposes the octave divided into 31 equal parts. Of these a whole tone, whether τ or t, (for he makes all his *tones* equal,) consists of 5, a limma (or an approximate, or *tempered* value of θ) = 3, the interval between each note and its sharp or flat = 2, and the diesis = 1. This gives the following scale of intervals.

(1) (1)♯ (2)♭ (2) (2)♯ (3)♭ (3) (4)♭ (3)♯ (4) (4)♯ (5)♭ (5) (5)♯ (6)♭ (6) (6)♯ (7)♭ (7) (1)♭ (7)♯ (1)
2 1 2 2 1 2 1 1 1 2 1 2 2 1 2 2 1 2 1 1 1

and by picking our notes among these, we may obtain a scale approaching extremely near to a perfect diatonic scale, whichever we may choose for our key-note.

250. Dr. Smith's system. Instead of dividing the octave into 31 equal parts, Dr. Smith proposes to divide it into 50, of which 8 shall constitute a tempered tone, and 5 a *limma*, or tempered value of θ, and the interval between each note, and its sharp or flat, shall = 3. This will give the sequence of intervals as below.

(1) (1)♯ (2)♭ (2) (2)♯ (3)♭ (3) (4)♭ (3)♯ (4) (4)♯ (5)♭ (5) (5)♯ (6)♭ (6) (6)♯ (7)♭ (7) (1)♭ (7)♯ (1).
3 2 3 3 2 3 2 1 2 3 2 3 3 2 3 3 2 3 2 1 2

This scale, he observes, approximates insensibly near to what he terms the system of equal harmony, a system, in our opinion, uselessly refined, and founded on principles for which the reader is therefore referred to his Work on *Harmonics*, (Cambridge, 1749.)

251. Temperaments adapted for the piano-forte. Either system, no doubt, will give very good harmony; but as on the piano-forte only 12 keys can be admitted, and as this instrument is now become an essential element in all concerts, and indeed the chief of all, a temperament *must* be devised which will accommodate itself to that condition. Of the division of the octave into 12 equal parts we have already spoken. Its fifths are all too flat, and its major thirds all too sharp; and the harmony is equally imperfect in all keys. But it has generally been considered preferable to preserve some keys more free from error, partly for variety, and partly because keys with five or six sharps or flats are comparatively little used, so that these may safely be left more imperfect, (which is called by some throwing the *wolf* into these keys.) Dr. Young recommends as a good practical temperament to tune downwards six perfect fifths from the fundamental note, and upwards six fifths equally imperfect among themselves. Or, as he observes is more easily executed, to make the third and fifth of the natural scale perfectly correct, to interpose between their octaves the second and sixth, so as to make three fifths equally tempered, and to descend from the key-note by seven perfect fifths, which will complete the scale. (*Lectures on Natural Philosophy*, vol. i. lect. 33.)

252. System of mean tones, or vulgar temperament. The system called by Dr. Smith that of mean tones, or the vulgar temperament, supposes the octave divided into five equal tones and two equal limmas, succeeding each other in the order $\alpha\,\alpha\,\beta\,\alpha\,\alpha\,\alpha\,\beta$ instead of $\tau\,t\,\theta\,\tau\,t\,\tau\,\theta$ as in the diatonic scale, and such that the third shall be perfect and the fifth tempered a little flat. These conditions suffice to determine α and β, for we have

$$\begin{aligned} 5\alpha + 2\beta &= 1 \text{ octave} = 3\tau + 2t + 2\theta, \\ 2\alpha &= 1 \text{ third} = \tau + t, \end{aligned}$$

and consequently

$$\alpha = \frac{\tau + t}{2}; \quad \beta = \theta + \frac{\tau - t}{4};$$

or, (since $\tau + t = 09691$, and $\tau - t = 00540$,) $\alpha = 04845$ and $\beta = 02938$. And since the interval from the first to the fifth of the scale in this system is $= 3\alpha + \beta = 2\tau + t + \theta - \frac{\tau - t}{4}$, it appears that this is *flatter* than a perfect fifth by the quantity $\frac{1}{4}(\tau - t)$, or a quarter of a comma. In this system the sharps and flats may be inserted by bisecting the larger intervals.

253. Logier system of harmony. Mr. Logier has lately, in a Work of great practical utility and very extensive circulation among musical students, endeavoured to place the interpolation of the intermediate notes between those of the natural scale on *à priori* grounds, by assuming the flat seventh (7)♭ as the seventh *harmonic* of the fundamental note (1), that is to say, the note produced by subdividing into seven equal parts the length of a string whose fundamental tone is (1), or at least one of the octaves of that note. There is something ingenious in this idea. In the first place it completes the series of the 10 first harmonics or notes, whose vibrations are multiples by 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, of those of the fundamental tone, which would thus be, in their order, (1), (1), (5), (1), (3), (5), (7)♭, (1), (2), (3), or octaves of these, and thus derives five out of the twelve notes of the octave from one uniform principle. Again, it gives something like a plausible reason for the prominent importance of the chord of the flat seventh (see Art. 230.) in music. This chord, in fact, which, if we take (1) for a fundamental note, consists of the notes (1), (3), (5), (7)♭, becomes in this point of view a *perfect concord*, consisting entirely of harmonics of (1), and its pulses will succeed each other on the ear in a cycle comprising four vibrations of the fundamental tone (1), five of the next (3), six of the next (5), and seven of the essential note (7)♭, as represented in fig. 35. The succession of pulses in the common chord is also represented in the same figure, and its regularity and pleasing variety, even to the eye, explains its agreeable effect on the ear. It is for musicians to say, whether they can make up their minds to regard the discord of the seventh in the light of a perfect concord or no. There is certainly nothing at all *discordant* in the vulgar sense of the word, *i. e.* unpleasant in its Sound, and so far it may be regarded as at least "*discordia concors*," but so far from possessing the essential character of a concord, that the ear is satisfied in hearing it, and expects and desires no more; there is no discord which calls so urgently for resolution. But, although it be true, that the seventh harmonic of the fundamental note lies between its natural

seventh and its octave, (it must lie somewhere,) yet, in fact, it is materially too flat a Sound to be used as a good flat seventh (7)♭. Its actual Sound coincides much more nearly with the (6)♯ of Huygens and Smith; and this defect, though it might be tolerated in quick compositions, and especially in piano-forte music where the notes are not held on, but degrade rapidly in intensity, would be at once felt in a slow piece on the organ. It is still worse if we derive *from it*, by a similar process, the intermediate note between (5) and (6), or (6)♭, and thence again (5)♭, and complete the chromatic scale of twelve notes by deriving (3)♭ according to the same principle from (4), and (2)♭ from (3)♭, according to Mr. Logier's system as laid down by him.* The (2)♭ thus derived would hardly be distinguished from (1) *natural*, or the (5)♭ from (4) *natural*, as the following scale will show, where the fractions represent the ratios of the vibrations of the notes above them to those of the fundamental tone (1).

(1),	(2)♭,	(2),	(3)♭,	(3),	(4),	(5)♭,	(5),	(6)♭,	(6),	(7)♭,	(7),	(8).
1,	$\frac{49}{48}$,	$\frac{9}{8}$,	$\frac{7}{6}$,	$\frac{5}{4}$,	$\frac{4}{3}$,	$\frac{343}{256}$,	$\frac{3}{2}$	$\frac{49}{32}$,	$\frac{5}{3}$,	$\frac{7}{4}$,	$\frac{15}{8}$,	2.

Sevenths, then, tuned on Mr. Logier's principle, will require a much more violent temperament than either fifths or thirds, either of which *might* be used as a means of introducing the intermediate notes; and the system must in consequence be abandoned, as must every system which professes to render musical arithmetic any thing more than a matter of convention and approximation.

We annex here, for comparison, a Table of the logarithmic values of the intervals from (1) the fundamental tone to all the other notes in the several scales of 21, or of 12 notes, according to the different systems and principles above mentioned.

The numbers marked thus (*) are what would be given by pushing the application of Mr. Logier's principle through the whole scale, and are inserted only to show the rapid progressive effect of flattening by a series of untempered harmonic sevenths.

Comparative Table of different scales of temperament, &c

Designation of Note.	Intervals in the perfect Diatonic Scale.			Diatonic Scale with its tones bisected.	System of mean tones or vulgar temperament, Art. [illegible]	System of equal Temperament, Art. 242.	Dr. Young's first System, Art. 251.	Dr. Young's second System, Art. 251.	Mr. Logier's Scale.	Huygens's System of 21 notes, Art. 249.	Smith's approximate System of 21 notes, Art. 250.	Mean Scale.
	Ratio.	Log.	Approx. Log.									
(1)	1	00000	0	0	0	0	0	5	0	0	0	0
(1)♯										19	18	
(1)♯ = (2)♭	—	—	—	25	24	25	23	23	9*			24
(2)♭										29	30	
(2)	$\frac{9}{8}$	05115	51	51	48	50	49	49	51	49	48	49
(2)♯										68	66	
(2)♯ = (3)♭	—	—	—	74	73	75	74	74	67			73
(3)♭										78	78	
(3)	$\frac{5}{4}$	09691	97	97	97	100	98	97	97	97	96	98
(4)♭										107	108	
(3)♯										117	114	
(4)	$\frac{4}{3}$	12494	125	125	126	125	125	125	125	126	126	125
(4)♯										146	144	
(4)♯ = (5)♭	—	—	—	150	150	151	148	148	127*			150
(5)♭										155	157	
(5)	$\frac{3}{2}$	17609	176	176	175	176	175	176	176	175	175	176
(5)♯										194	193	
(5)♯ = (6)♭	—	—	—	199	199	201	199	199	185*			199
(6)♭										204	205	
(6)	$\frac{5}{3}$	22185	222	222	223	226	224	224	222	223	223	224
(6)♯										243	241	
(6)♯ = (7)♭	—	—	—	247	247	251	250	250	243			248
(7)♭										252	253	
(7)	$\frac{15}{8}$	27300	273	273	272	276	273	273	273	272	271	273
(8)♭ = (1)♭										282	283	
(7)♯										291	289	
(8) = (1)	2	30103	301	301	301	301	301	301	301	301	301	301
Comma ...	$\frac{81}{80}$	00540	$5\frac{1}{2}$									
Limma = θ	$\frac{16}{15}$	02803	28									
Minor tone t	$\frac{10}{9}$	04576	46									
Major tone τ	$\frac{9}{8}$	05115	51									
Minor third	$\frac{6}{5}$	07918	79									
Major third	$\frac{5}{4}$	09691	97									
Fourth	$\frac{4}{3}$	12494	125									
Fifth......	$\frac{3}{2}$	17609	176									

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* *System of the Science of Music and Practical Composition*, p. 50. We should, however, remark that the powerful descending tendency of the chord of the flat seventh is necessarily much augmented by tuning the (7)♭ too flat.

255. Remarks. The last column contains a scale derived by taking the mean of all those in the other columns which differ in the principle of their origin, (excepting those in the tenth column, for obvious reasons.) It approaches through its whole extent so near to the system of mean tones in col. 6, as to be quite undistinguishable from it; the deviation in no case exceeding a single unit, or a fiftieth part of a tone. This system, then, though the most inartificial, is probably as good as any which the nature of music admits, holding a sort of mean between the advantages and defects of all the rest. Consult on Temperament and on Musical Scales, Salinas, *de Musicâ*, (1577;) Zarlino, *Dimostrazione Armoniche*, and *Istituzione Armoniche;* Deschales, *Cursus Mathematicus de Progressu Musico;* Sauveur, *Mém. Acad. Par.* 1700; Smith, *Harmonics;* Pepusch, *Phil. Trans. Lond.* 1746; Farey, *Phil. Mag.* xxviii.; Young's Lectures and his Catalogue of Authors in vol. ii.

256. Expression of the principal chords by chromatic numbers. For one purpose, that of explaining to beginners the notes, intervals, and rules of music, the system of equal temperament, which supposes the octave divided into 12 equal parts, which in this system only are *really* semitones, has the advantage of avoiding all discussions and puzzling explanations on the nature of harmony, as it makes all intervals which are called by the same name strictly alike. Regarding the octave as consisting of 12 semitones, and designating its notes in succession, beginning with the fundamental note, by 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, &c. it will not be amiss if we write down in this notation the principal scales, chords, &c. which occur in music.

Notation of chromatic numbers explained.

Chromatic scale	0,	1,	2,	3,	4,	5,	6,	7,	8,	9,	10,	11,	12.
Diatonic scale	0,		2,		4,	5,		7,		9,		11,	12.
Minor scale ascending	0,		2,	3,		5,		7,		9,		11,	12.*
Minor scale descending	12,		10,		8,	7,		5,		3,		2,	0.
Common major chord................					0,	4,		7,					
Minor chord					0,	3,		7,					
Fundamental discord of the flat seventh .					0,	4,		7,		10.			
Chord of the added sixth (Logier, *Ex.* 117.)					0,	4,		7.		9.			
Chord of the ninth					0,	2,		4,		7.			
Minor chord with added sixth					0,	3,		7,		9.			
Diminished seventh					0,	3,		6,		9.			
Chord of the sharp sixth (Logier, *Ex.* 197.)					0,	2,		6,		8.			

257. Triads, tetrachords, pentachords, and hexachords. These are all the chords, consisting of four different notes (or tetrachords) in common use in music. As to pentachords, such as what have been called the major and minor ninth, and compound sharp sixth, whose notes are respectively 0, 2, 4, 7, 10; 0, 1, 4, 7, 10, and 0, 4, 6, 7, 10, (Logier, *Ex.* 212, 158, and 202.) they are, in fact, only chords of the seventh (0, 4, 7, 10) with a fifth note violently forced in; the effect being to distract the ear by a harsh discord, out of which it is but too glad to escape, to be very nice about its resolution. In like manner the pentachord 0, 2, 5, 7, 11, or the chord of the eleventh, is the chord of the seventh accompanied by the sub-dominant of its radical note, and thus anticipating its resolution; as is easily seen by adding 5 to each of its component numbers, when it becomes 5, 7, 10, 12, 16, or, which is the same thing, 5, 7, 10, 0, 4, or 0, 4, 5, 7, 10, (since the addition or subtraction of 12 semitones, or an octave, does not alter the character of the Sounds;) and in the same way may other pentachords be formed, as 0, 3, 4, 7, 10; 0, 4, 7, 8, 10; (*Ex.* Clementi's *Sonatas*, Op. 22. son. 1. bars 68, 69.) 0, 4, 7, 9, 10. As to such combinations as the hexachord 0, 2, 5, 7, 9, 11, or "the chord of the 13th," (Logier, *Ex.* 273.) in which only one note of the whole natural scale (4) is wanting, they are abominable jangles, as offensive to a simple and unvitiated ear, as the mixed flavours and *haut-gouts* of the palled epicure are to an appetite not spoiled by artificial excitement.

258. The reader who would try these chords on the piano-forte, has only to place his finger on any black or white key as a radical note, and also on the keys distant from that one by the numbers of semitones (reckoning upwards) marked in the designation of the chord as above. Thus to produce the chord of the sharp sixth having D♭ for its radical note. The note 0 corresponds to D♭, 2 to E♭, 6 to G♭, and 8 to A♭, which are, therefore, the notes to be struck together, (to whatever octaves of the instrument they may be afterwards transferred, as the rules of composition may dictate,) and so of others.

259. Inversions of a chord. Any of these chords is said to be inverted, when, instead of taking 0 for the initial note, we regard any other of its component Sounds as such. On the system of notation here employed, (which we will term the system of *Chromatic numbers* to distinguish it from those in Art. 234, to which the term *Diatonic numbers* may be applied,) nothing is easier than to represent the inversions of any chord. Take, for instance, the major concord, 0, 4, 7. The addition of 12 (the octave of 0) does not change the chord; so that it may be written thus, 0, 4, 7, 12, or, leaving out the first note, and adopting 4 for the initial note, 4, 7, 12. If, now, we choose to regard the note 4 as an initial one, and count upwards from it, we have only to subtract 4 from each of these numbers, and we get 0, 3, 8 for a first inversion. Appending 12 to this again, and rejecting the initial 0, it becomes 3, 8, 12, from each of which numbers subtracting 3 we get the second inversion, 0, 5, 9. If we repeat the same process on this we fall back on the original combination. Thus we see that this chord admits of only two inversions. Again, suppose we would find the inversions of the chord of the added sixth, or 0, 4, 7, 9. The process will stand thus:

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* 8, 11, 12, according to Logier and others. *Vide*, on this point, Weber's excellent and scientific work, *Tonsetzkunst*.

```
 0, 4, 7, 9, 12
    4, 7, 9, 12
    4, 4, 4,  4
    -----------
    0, 3, 5,  8       1st inversion.
       3, 5,  8, 12
       3, 3,  3,  3
       ------------
       0, 2,  5,  9       2d inversion.
          2,  5,  9, 12
          2,  2,  2,  2
          -------------
          0,  3,  7, 10       3d inversion.
              3,  7, 10, 12
              3,  3,  3,  3
              -------------
Original chord again....  0,  4,  7,  9
```

Thus we see that this chord admits of three distinct inversions. In general, a triad admits of three forms, or one original, and two inversions, a tetrachord of 4, a pentachord of 5, and so on; though it may happen, as in the case of the triad 0, 4, 8, or the tetrachords 0, 2, 6, 8, and 0, 3, 6, 9, that some or all of the inversions reproduce the original chord.

260. If we go through the same process for other triads and tetrachords, we get their inversions as follows:

Triads.

	1st form, or radical.	2d form, or 1st inversion	3d form, or 2d inversion
Major concord....................	0, 4, 7	0, 3, 8	0, 5, 9
Minor concord....................	0, 3, 7	0, 4, 9	0, 5, 8
Equivocal triad, or double third......	0, 4, 8	0, 4, 8	0, 4, 8

Tetrachords.

	1st form.	2d form.	3d form.	4th form.
Seventh........................	0, 4, 7, 10	0, 3, 6, 8	0, 3, 5, 9	0, 2, 6, 9
Added sixth......................	0, 4, 7, 9	0, 3, 5, 8	0, 2, 5, 9	0, 3, 7, 10
Ninth..........................	0, 2, 4, 7	0, 2, 5, 10	0, 3, 8, 10	0, 5, 7, 9
Minor added sixth................	0, 3, 7, 9	0, 4, 6, 9	0, 2, 5, 8	0, 3, 6, 10
Triple fifth.....................	0, 2, 7, 9	0, 5, 7, 10	0, 2, 5, 7	0, 3, 5, 10
Equivocal.				
Diminished seventh................	0, 3, 6, 9	0, 3, 6, 9	0, 3, 6, 9	0, 3, 6, 9
Sharp sixth......................	0, 4, 6, 10	0, 2, 6, 8	0, 4, 6, 10	0, 2, 6, 8

Pentachords.

	1st form.	2d form.	3d form.	4th form.	5th form.
Minor ninth (Logier, *Ex.* 158.)	0, 1, 4, 7, 10	0, 3, 6, 9, 11	0, 3, 6, 8, 9	0, 3, 5, 6, 9	0, 2, 3, 6, 9
Compound sharp sixth (Log. *Ex.* 202)	0, 4, 6, 7, 10	0, 2, 3, 6, 8	0, 1, 4, 6, 10	0, 3, 5, 9, 11	0, 2, 6, 8, 9
Major ninth (Log. *Ex.* 212).......	0, 2, 4, 7, 10	0, 2, 5, 8, 10	0, 3, 6, 8, 10	0, 3, 5, 7, 9	0, 2, 4, 6, 9
Eleventh (Log. *Ex.* 267)..........	0, 4, 5, 7, 10	0, 1, 3, 6, 8	0, 2, 5, 7, 11	0, 3, 5, 9, 10	0, 2, 6, 7, 9

261. Remarks. These chords, thus figured and arranged, afford room for some remarks of importance. In the first place we observe that they all, with the exception of the triad 0, 4, 8, and the tetrachords 0, 2, 6, 8, and 0, 3, 6, 9, contain a major or minor concord, 0, 4, 7, or 0, 3, 7. This seems necessary to give any chord a decided character; for the excepted cases above specified have all an equivocal effect and leave the ear in suspense whither the modulation will lead. For with respect to the chords 0, 4, 8, and 0, 3, 6, 9, they divide the octave equally, the one into three major thirds, the other into four minor, as is immediately seen if we write them thus, 0, 4, 8, 12, and 0, 3, 6, 9, 12. In consequence, all their inversions are similar to the original chords, and they are equally related, the former to three, and the latter to four different keys, and may lead into either of them, according as a

Aliquot division of the octave.

note added so as to form a dominant seventh, or anticipative sub-dominant, or some other powerful leading interval, or with either of their component notes, shall decide. This is one mode of conceiving the chord of the minor ninth, which may be either regarded as a chord of the seventh, with the first semitone 1 added, (as in its first form above,) or as a diminished seventh, 0, 3, 6, 9, with the note 11 added, as in the first inversion, with 8 as in the second, or with 2 as in the third, either of which makes a flat seventh with one or other of its notes.

262. Equivocal chords.

The transitions thus produced by means of the tetrachord 0, 3, 6, 9, are peculiarly graceful. It is otherwise with the equivocal triad 0, 4, 8, which is essentially harsh and unpleasing, (in spite of the *perfect* harmony which, if we were to leave out the octave and tune its thirds perfect, its members must produce with each other, since it would be in that case an absolute concord.) Whether this chord, or that which we have called the triple fifth, has ever been, or can be, used in music, we know not, though perhaps, properly handled, it might become a source of modulation; which, however, is for practical musicians to consider.

263. Relations between the tetrachords and pentachords.

The chord of the sharp sixth 0, 2, 6, 8 is also equivocal, arising from a double aliquot division of the octave, and the two last of its inverted forms being therefore merely repetitions of the two first. Like the diminished seventh, then, it holds the ear in suspense, till the addition of another note decides the course the modulation shall take, and the chord so arising is the compound sharp sixth. (See the inversions of this latter chord compared with those of the former.)

In like manner the *major* ninth contains both a ninth and a seventh, though not the other accompaniments of the seventh. The tetrachord which (for want of another name, we have called the minor added sixth, from its being a minor concord with a sixth added) is related to this compound ninth in the same way as has just been pointed out with respect to the chords of the diminished seventh and minor ninth, and to those of the sharp sixth and compound sharp sixth; the character of the tetrachord, which is undecided of itself, and admits of more than one resolution, being determined by the note added in the pentachord so as to form a dominant seventh with some one or other of its other members.

264. Chord of the eleventh examined.

The chord of the eleventh offers room for a remark analogous to what we have before observed (Art. 262.) respecting the equivocal triad 0, 4, 8. It contains within itself three fifths and a major third; as is obvious if we take its fifth form 0, 2, 6, 7, 9, and transfer the notes 2, 6, and 9 to the next octave above, when it will become 0, 14, 18, 7, 21, or 0, 7, 14, 18, 21. The notes 0, 7, 14, 21, in this arrangement, make fifths with each other, and the note 18 forms with 14 a major third; if, then, the intervals were tuned perfect, their vibrations would succeed each other in a regular cycle, but if the cycle formed by two perfect thirds, which requires only 25 vibrations of its highest note, or 16 of its lowest to complete it, is too complex for the ear to relish, the cycle of three perfect fifths, which requires 27, will already be too complex; and if we add to this a major third, the ear will lose all ense of recurrence, and only discord will result.

265. Chords of the ninth and seventh analysed.

But to place this in clearer evidence, we need go no further than the chord of the ninth, which, when written thus, 0, 4, 7, 14, manifests a major third, (0, 4,) a fifth, (0, 7,) and a double fifth, (0, 7 + 7,) of the fundamental note, and therefore, if tuned perfect, would excite a sense of perfect concord, were not the period of recurrence of the vibrations too long for the ear to seize; and a similar remark applies to the discord of the seventh, which consists of a major third, a fifth, and a double fourth, from the fundamental tone (0, 4, 7, 5 + 5.) It may be that the harshness of the triad 0, 4, 8, and of the tetrachord 0, 2, 7, 9, the former consisting, if tuned perfect, of a third and double third, the latter of a fifth, a double fifth, and a triple fifth, may arise from an imperfect, or obscure, and therefore unsatisfactory, perception of the cycles of their vibrations by the ear, the former, as before remarked, occupying 25, and the latter 27, single vibrations of the highest note. But it is time to leave these speculations.

§ V. *Of the Sonorous Vibrations of Bars, Rods, and Plates*

266. References.

The vibrations of all bodies, if of a proper degree of frequency, and of sufficient force to be communicated through the air, or any other intermedium, to our organs of hearing, produce Sounds whose pitch depends on their frequency; and their force and quality on the extent and other mechanical circumstances of the vibrations, and the nature of the vibrating body. The mathematical investigation of these vibratory motions is altogether foreign to our purpose. It is a branch, and one of the most intricate and least manageable branches, of Dynamics, and we shall, therefore, refer our readers for its theory and details to the writings of the various eminent authors who have discussed it. See Bernouilli, *Com. Petrop.* vol. xiii. On the Vibrations of Laminæ; and *Nov. Com. Petrop.* vol. xv.; Euler, *Com. Petrop.* vol. vii., *Nov. Com.* vol. xvii., and *Act. Petrop.* vol. iii. On the Vibrations of Plates; Riccati, *Soc. Ital.* vol. i. p. 444; Lexell, On the Vibrations of Rings, *Act. Petrop.* 1781; Lambert, On the Sounds of Elastic Bodies, *N. Act. Helv.* vol. i.; J. Bernouilli, On the Vibrations of Rectangular Plates, *N. Act. Petrop.* 1787; Biot, On the Vibrations of Surfaces, *Mem. Inst.* vol. iv.

267. Various ways in which solids may vibrate.

A solid body may vibrate, either in consequence of its inherent elasticity, by which it tends to return to its own proper figure and state when forcibly deranged, or in consequence of an external tension. To the former sort of vibrations belong those of rods, tuning-forks, plates, rings, bells, gongs, and vessels of all shapes, or generally, of all solid masses which *ring* when struck. To the latter, those of vibrating strings and membranes, such as the parchment of a drum or tambourin, &c. But, further, a solid may vibrate by its own proper elasticity in two very different ways. First, an undulation may be propagated through it, as through an elastic compressible medium, and, in this case, the waves will consist of alternate strata of condensed and rarefied solid matter, precisely similar to those of an elastic fluid. If the solid be homogeneous, such as the metals, glass, &c., the elasticity being the same in all directions, the waves will be propagated from the centre of disturbance, according to exactly the same laws as in a mass of air of the same shape. But if crystallized, this may not be the case, or the vibrations instead of being in the direction of the propagated wave, may be transverse, or oblique to it, or may even not be confined to one plane, but may be performed in circles or ellipses. See Article Light.

268. Longitudinal vibrations of a straight rod.

If a straight rod of glass, or a metal, to be struck at the end in the direction of its length, or rubbed lengthways with a moistened finger, it will yield a musical Sound, which, unless its length be very great, will be of an extremely acute pitch; much more so than in the case of a column of air of the same length. The reason of this is the greater velocity with which Sound is propagated in solids than in air. Thus the velocity of propagation in cast-iron being 10½ times that in air, a rod of cast-iron so excited will yield for its fundamental note a Sound identical with that of an organ pipe of $\frac{1}{10\frac{1}{2}}$ of its length stopped at both ends, or $\frac{1}{21}$ of its length if open at one end. See § III., all the details of which are applicable to the present case. To such vibrations, Chladni, who first noticed them in long wires, has applied the term longitudinal. (*Art. Acad.* Erfurt, 1796.) To produce the harmonics of such a rod or wire he held it lightly at the place of one of its intended nodes between the finger and thumb, and applied the friction in the middle of one of the vibrating segments. If the rod be of metal, the friction which he found to succeed, was that of a bit of cloth sprinkled with powdered rosin, if of glass, the cloth, or the finger, may be moistened and touched with some very fine sand or pumice powder. It may be observed here, that, generally speaking, a fiddle-bow well rosined is the readiest and most convenient means of setting solid bodies in vibration. To educe their gravest or fundamental tones, the bow must be pressed hard and drawn slowly, but for the higher harmonics, a short swift stroke with light pressure is most proper. In all cases the point intended to be a node must be lightly touched with the finger, and the vibration must be excited (as above said) in the middle of a ventral segment. Such is the case analysed by Chladni. In general, however, the vibrations of a cylindrical rod or tube so excited are more complex. See Art. 286, Index, Art. *Longitudinal Vibrations.*

How produced.

269. Transverse vibrations of a rigid rod.

But by far the most usual species of vibration executed by solid bodies is that in which their external form is forcibly changed, and recovered again by their spring. The simplest case is that of a rod executing vibrations to and fro in a direction transverse to its length. This case has been investigated mathematically by D. Bernouilli and Euler, as also by Riccati; (see the list of authors above cited, Art. 266;) and their results have been compared with those of experiment by Chladni, *Acoust.* sec. 5, and found correct. The cases enumerated by Chladni are six in number.

Fig. 36. Enumeration of cases.

1. When one end of the rod is firmly fixed in a vice or let into a wall, the other quite free. In this case the curvature assumed by the rod in its vibrations must of necessity have its axis or position of rest for a tangent, as fig. 36.

Fig. 37. 2. One end *applied* or pressed perpendicularly against an obstacle, the other free. In this case, the *excursions* of the applied end to and fro are prevented by the friction and adhesion to the obstacle, but the axis is not of necessity a tangent. See fig. 37.

Fig. 38. 3. Both ends free. Fig. 38.

Fig. 39. 4. Both ends applied. Fig. 39

Fig. 40. 5. Both ends fixed. Fig. 40.

Fig. 41. 6. One end fixed, the other applied. Fig. 41.

270. Examination of one of them. Figs. 39, 43, 44.

All these cases have been examined by Chladni at length. We shall, however, select only the fourth case where both ends are applied, because it will afford room for an important remark. In this, then, the several modes of vibration corresponding to 1, 2, 3, 4, 5 vibrating or ventral segments of the rod will be as in figs. 39, 43, 44. Now these are similar to the curves which would be assumed by a vibrating string under the same circumstances of subdivision. But the notes produced are very different. For whereas in the case of a string the vibrations of the successive harmonics are represented by 1, 2, 3, 4, 5, &c.; in that of a rod they are represented by the *squares* of these numbers 1, 4, 9, 25, &c., which correspond to *double* the former intervals. In all the other cases the series is still less simple.

271. Remark on the origin of harmony.

This alone suffices to shew the insufficiency of any attempt to establish, as some have wished to do, the whole theory of harmony and music on the aliquot subdivision of a vibrating string. Had vibrating rods or steel springs (which yield an exquisite tone) been always used instead of stretched chords, such an idea would never have suggested itself, yet no doubt our notions of harmony would have been what they now are. The same remark applies still more forcibly to the modes of subdivision of vibrating surfaces, which in many cases have their harmonics altogether irreducible to any musical scale.

272. Vibrations of a rectangular plate in their simplest case.

A rectangular plate may be regarded as an assemblage of straight rods of equal length, ranged parallel to each other. Supposing such an assemblage all set in vibration similarly and at once, they will retain their parallel juxtaposition during their vibration, and may, therefore, be supposed to adhere, and form a plate. Consequently, among the possible series of vibrations of a rectangular plate will be found all those of a rigid rod. Accordingly, when fixed, (for instance,) by one of its edges in a vice, with its plane parallel to the horizon and strewed over with sand, if it be set in vibration by a fiddle-bow and touched in one of its possible nodes, its subdivisions will be rendered visible to the eye, by the sand being thrown away from the vibrating parts and accumulating on those at rest. Thus the plate will be crossed transversely by a series of *nodal lines* marked in sand, and whose distances from each other and from the ends of the plate may be measured at leisure.

273. Other cases.

But besides these, rectangular plates are susceptible of other modes of subdivision, having two sets of nodal lines, straight or curved, crossing at right angles, or otherwise, and dividing the plate into smaller plates, each vibrating in its middle, and at rest at its edges, and every two contiguous plates separated by a nodal line making their simultaneous excursions on contrary sides of their state of rest.

274. To produce these subdivisions, and to render them visible, take a rectangular plate (for simplicity we will

Mode of producing their several subdivisions.

suppose it a square) of glass, or metal, of an even thickness, not too thick, and holding it firm between the points of the finger and thumb of the left hand, or between two points of a clamp-screw covered with cork or leather so as not to jar, taking care to keep the pressure confined to as small a space as possible, draw a rosined bow over the edge, which should be smoothed and a little rounded. If then the point where it is held be the centre of the plate, and the bow be applied close to one of the angles, sand strewed over it will arrange itself on the two diameters which divide it into four equal squares as in fig. 44. Each of these, in the act of vibration, becomes a surface of double curvature, and their motions are contrary to each other; those marked + making their excursions on one side of the plane of repose, while those marked − are on the other. This mode of vibration corresponds to the gravest tone produced by the plate.

First mode of a vibration of a square plate. Fig. 44.

275. Second mode. Fig. 45.

If, the plate being still held in the centre, the bow be applied at the middle of one side, the sand will occupy the diagonals of the plate, which are the nodal lines corresponding to this mode. In this, as in the former case, the plate subdivides itself into four equal vibrating segments as in the fig 45, but the tone is different, being a fifth higher than in the former case, the distribution of the inertia with respect to the elastic power of the plate being such as to admit a quicker motion.

276. Fig. 46. Other modes.

If the plate be held at *a*, the intersection of two nodal lines fig. 46, and the bow be still applied at the middle of one side, or at the angle adjacent to *a*, the plate will vibrate as there represented. In this subdivision, the four small squares at the angle and the large one at the centre vibrate on one side, or negatively, while the four intermediate oblong rectangles adjacent to the sides vibrate positively.

277. Fig. 47—93 Modes of vibration of square and circular plates observed by Chladni.

These instances may serve to show the mode of proceeding in more complicated cases, and with plates of other figures. Among these, circular ones hold the chief place both for symmetry and variety. The examples, figs. 47—93, are selected from those described by Chladni, who has determined by experiment the tones corresponding to each mode of division in plates of a great variety of figures. Of these we shall only give some examples in the case of a square plate, of which we shall suppose the gravest or fundamental tone to be represented by 1. This premised, if we regard the plate as subdivided into $n \times n'$ rectangles by n nodal lines parallel to one side, and n' parallel to the other, the notes corresponding will be as in the following Table:

Series of Sounds produced by a square plate.

		Values of n.					
		0	1	2	3	4	5
Values of n'.	0				$(1)'''\sharp$ +		
	1		(1)	$(3)''$		$(3)^{\text{iv}}\flat$ −	
	2		$(3)'''$	$(3)'''\flat$ −	$(7)^{\text{iv}}$		$(1)^{\text{v}}\sharp$ +
	3	$(1)'''\flat$ +		$(7)^{\text{iv}}$	$(4)^{\text{v}}$	$(7)^{\text{v}}$	
	4		$(3)^{\text{iv}}\flat$ −		$(7)^{\text{v}}$	$(3)^{\text{v}}\flat$	
	5			$(1)^{\text{v}}\sharp$ +			

278. Fig. 94—123.

The vibrations of triangular, hexagonal, elliptic, and semicircular plates have also been investigated by Chladni, and fig. 94—123 exhibit some out of a great variety of nodal figures, to which they give rise in their various modes of vibration.

PART III.

§ I. *Of the Communication of Vibrations and of the Vibrations of Systems.*

Sound.

279. Savart's researches on the vibrations of solids.

The subject of the sonorous vibrations of solids has recently been taken up in a more general and extended point of view by M. Felix Savart, in a series of Memoirs communicated by him to the Royal Academy of Sciences of Paris, and of which copies, or copious extracts, are printed in the *Annales de Chimie*. We regret that the narrow limits which remain to us in this volume, will allow little more than a slight sketch of the contents of the principal of these most interesting papers, the whole of which are models of experimental research, and indeed, so full of new, curious, and instructive matter, that it is next to impossible either to condense or abstract them; for which reason we earnestly recommend our readers, who may be led to take an interest in the subject of this Essay, not to content themselves with the meagre statements here offered, but to procure and study diligently the original Memoirs.

280. Method of communicating a given vibration to a given point of a solid.

In order to a regular analysis of this intricate subject, it was first requisite to obtain some certain mode of communicating to any given point of a solid vibrations confined to one plane, and whose period of recurrence, as well as the plane in which they were performed, and the amplitude of their excursions, could be varied at pleasure. The vibrations of a stretched string set in motion by a fiddle-bow, afford the means of doing this. Such are necessarily confined to the plane in which the motion of the bow is performed, because any vibratory motion out of this plane is prevented, or immediately stifled by the pressure of the bow; and as the plane of its motion may be varied at pleasure, and the amplitude of excursion may be increased or diminished by a change of pressure, and velocity of stroke, all the requisite conditions are here obtained. Accordingly, if the vibrating part of such a string be brought to press on a solid not too massive, or if the end of the string be attached to a point in the solid, M. Savart has found that the regularly repeated impulses of the string are transferred to the solid with perfect fidelity.

281. Vibrations of a violin string how communicated to the wood. Fig. 124.

A familiar example of this communication of impulses is found in the violin. In that instrument, fig. 124, the strings which are stretched from end to end of it, are divided into two uneqal parts by the bridge, A, on which they all press strongly, and at the same time rest in small notches, so as not to slip laterally on it. The portion, B, of the string which lies towards the handle, C, of the instrument, is free, and is set in vibration by the bow in its own plane; but that on the other side of the bridge, D, is loaded with a mass of horn or whalebone, E, to which all the other strings are also attached, and which, being only *tied* to the wood-work, cannot propagate the vibrations of any one string sounding separately, by reason of the contradictory and unequal tensions of the other three. Thus the bridge is in fact acted on only by the vibrations of that part, A B C, of the string which is crossed by the bow, as if it terminated abruptly at its point of pressure, A. These vibrations constantly tend, therefore, to tilt the bridge laterally backwards and forwards, and to press up and down alternately the two little prominences or feet, F G, by which it rests on the belly of the violin. It, therefore, sets the wood of the upper face in a state of regular vibration, and this again is communicated to the back through a peg set up in the inside of the fiddle, and through its sides, called the *soul* of the fiddle, or its *sounding post*. In consequence, if the upper surface be strewed with sand, it will assume a regular arrangement in nodal lines when the bow is drawn; and the same subdivision is also observed in the wood of the under surface, if the sounding-post be exactly placed in the centre of symmetry of the nodal figures. The experiment can hardly be made, however, with a common fiddle, by reason of the convexity of its surface, on which sand will not rest; but if one be constructed with plane boards, or if, abandoning the fiddle, a string be stretched on a strong frame over a bridge, which is made to rest on the centre of a regularly formed plate or disc of metal or wood, strewed with sand, the surface thus set in vibration by the string will be seen to divide itself by regular nodal figures.

Vibrations of the wood, how observed.

Plates made to vibrate by communication with strings.

282. Joint vibrations of a plate and string as a system.

Now M. Savart has observed this remarkable fact, *viz*. that if the tension or length of the string thus placed in vibratory communication with a plate, be changed, so as to vary the note it speaks, the nodal figures on the plate undergo a corresponding variation, and the plate *still* vibrates in unison with the string; or, which is the same thing, the two, together with the interposed bridge, form a vibrating system, in which, though the vibrations of the several parts are necessarily very different in their nature and extent, yet they have all the same periods. This experiment is very important. It shows that the Sounds of such thin plates are not like those of strings confined to certain fixed harmonics, but, according to the forms of their nodal lines, and the proportions of the vibrating areas in opposite states of excursion, may assume any assigned period; in other words, given the vibrating plate and the pitch, a nodal figure may be described on it, which shall correspond to that pitch, and the plate (with more or less readiness, however) is always susceptible of such a vibration as shall yield that note, and produce that nodal figure. How far this proposition is general, and with what limitations it is to be understood, we shall soon see. Meanwhile this remark, it will be observed, furnishes a complete explanation of the effect of sounding-boards in musical instruments. It is not, as some have supposed, that there exist in them fibres in every state of tension, some of which are therefore ready to vibrate in unision with any proposed Sound, and, therefore, reinforce it. Such a cause could at best produce but a very feeble effect. It is the *whole* board which vibrates as part of a system with every note, and (as vibrations may be superposed to any extent) the same sounding-board may at once form a part of any number of systems, and vibrate in unison with every note of a chord. Still some modes will always be more difficult than others, and no sounding-board will be perfectly indifferent to all Sounds.

283. Longitudinal vibrations of a rod employed to communicate vibrations to solids. Chladni's *Euphone*.

The longitudinal vibrations of a rod of glass, excited by rubbing it with a wet cloth, may also be used to excite vibrations in a given point of a solid perpendicular to its surface, by applying its end to it, or cementing it to the solid by mastic. In this way Chladni applied it to draw forth the Sounds of glass vessels, (which when hemispherical, and of sufficient size and even thickness, are remarkably rich and melodious,) in an instrument which he called the *Euphone*, exhibited by him in Paris and Brussels. The principle of this instrument was at the time concealed; but the enigma was subsequently solved by M. Blanc, who on his part independently made the same remark, and applied it to a similar purpose.

284. Mutual influence of a vibrating disc and a rod connected wit it. Of two clocks placed near together. Of organ-pipes nearly in unison.

If the solid (a circular glass disc for instance) to which such a vibrating rod or tube is fastened, be of small comparative dimensions, its vibrations are commanded by those of the rod, and the Sound yielded will be that of the rod alone; and *vice versâ*, if the disc be large, and the rod small, the note sounded will be that of the disc, which will entirely command the rod; but in the intermediate cases, both M. Savart and M. Blanc have observed, the note will be neither that of the disc or the rod separately, but the two will vibrate together as a system, each yielding somewhat to the other. It is a case exactly analogous to that of a reed-pipe, in which the reed and column of air mutually influence each other's note. See Art. 199. This mutual influence of propagated motion, by which two periodically recurring impulses affect each other's period, and force themselves into synchronism, extends to cases where at first sight it would hardly be suspected. Thus Ellicot observed that two clocks fastened to the same board, or even standing on the same stone pavement, beat constantly together, though when separated their rates were found to differ very considerably; and Breguet has since made the same remark on watches. Thus also two organ-pipes vibrating side by side, if very nearly in unison, will under certain circumstances force themselves into exact concord, as has been observed by Hudlestone, (Nicholson's *Journal*, i. 329.) and lately recalled to notice by some experiments made in Copenhagen. The experiment with the disked tuning-fork and pipe, related in Art. 204., may here again be referred to.

285. Fig. 125. Vibrations communicated between two plates by a rod.

The longitudinal vibrations of a rod have also been used by M. Savart, to communicate vibrations from one solid to another; as for instance, from the upper to the under of two circular discs cemented at their centres to the two ends of the rod, at right angles to their planes, as at fig. 125. If the two discs be of the same dimensions and materials so as to yield, when separately vibrating, the same note, the vibrations of one of them, (the upper for instance,) excited by a bow, will be exactly imitated by the other, and sand strewed over both will arrange itself in precisely the same forms in both discs, and that, into whatever number of vibrating segments that immediately excited be made to subdivide itself. But if the discs separately do not agree in their tones, the system may yield a tone intermediate, and each being differently forced from its natural pitch, the nodal figures on them will then no longer correspond.

286. State of vibration of the connecting rod examined. Fig. 126.

The state of vibration in which the molecules of the connecting rod are thrown in such cases, deserves a nearer examination. For simplicity let us suppose the discs equal, the rod cylindrical, and the vibration of the system such that each disc shall subdivide itself into four quadrantal segments. In this case it is clear that as the form assumed at any instant by the upper disc is undulated or wrinkled, as represented in fig. 126, the section of the rod in immediate contact with it, and which obeys all its motions, must assume a similar form, and so of all the rest. Thus if we conceive the rod split into infinitesimal columns, parallel to its axis, all the columns in two opposite quadrants will be ascending, while those in the other two are descending; and thus the two corresponding opposite quadrants of the lower plate will be drawn upwards, while the alternate ones are forced downwards, giving a similar distortion to its figure, and disposing it to a similar vibration only. It will depend on the length of the rod, and the time taken by an undulation to run over its length, compared with that of a vibration of either disc, whether the *phases* of vibration in the two discs shall be the same at the same instant or not. It may happen that, for instance, the quadrant, D B, of the upper disc shall have completed its downward motion, and begun to return before the pulsation propagated through the rod has arrived at the lower disc; and in that case the corresponding quadrants of the two discs will be always in opposite phases of their periodic motion. But the nodal lines will of necessity correspond in both.

287. Case where the discs are unequal.

When the two discs are unequal, the propagation of the pulses through the rod must of course cease to be uniform, and each section of it down its whole length will have its own peculiar law of form and motion, which it is beyond our power to investigate. In that case its molecules must have lateral as well as vertical motions, and its vibrations must be partly *longitudinal* and partly *twisting*, in a way easier imagined than described. If the discs be dissimilar in form as well as unequal in dimension, the vibrations of the connecting rod will of course be very complicated.

288. M. Savart's violins.

These principles have been applied by M. Savart, and apparently with success, (as appears by the very able report of M. Biot on his Paper,) to the improvement of violins, and the construction of these delicate instruments on scientific and experimental grounds. Every one is aware of the difficulty of procuring perfect violins, and the enormous prices they bear, so that fixed rules, by which any ordinary artist can with certainty produce an excellent one, are evidently highly valuable. We long to see M. Savart's construction tried in this country, but must refer to his Paper (*Annales de Chimie*, vol. xii. p. 225, &c.) for the details.

289. Longitudinal vibrations of a rod further examined.

It appears from what we have said, that the motions of the molecules of a rod which communicates the vibrations of one disc to another, or, more generally, which vibrates longitudinally by any exciting cause, are not of necessity analogous to those of the air in a cylindrical pipe, at least not to that simple case of the latter vibrations, which we have heretofore considered in our 3d Section. The several transverse sections of such a rod, in the act of vibration, do not necessarily merely advance and recede longitudinally, but may become curves of double curvature; in short, such a rod may be considered as an assemblage of vibrating discs, ranged along a common axis, along which

Origin of nodal surfaces.

they may, it is true, be also carried backwards and forwards with a vibratory motion, while at the same time their flexure is changing from convex to concave, and *vice versâ*. Now it may happen that a point, or a line, (straight or curved,) in any one of such discs, may be advancing in the direction of the axis in consequence of the bodily motion of the whole disc, while, in virtue of its flexure in the act of changing its figure, it may be receding; and this advance and recess may so balance each other, that the point or line shall be at rest. If this be true at one instant, it will be so at all instants, because the vibrations have all one period, and follow the same law of increase and decrease in their phases. Thus we have a nodal point, or a nodal line; and as each disc, by reason of the law of continuity, must have a similar one, the assemblage of such lines will mark out within the rod a *nodal surface*, dividing it into separate solids whose molecules on either side of such surface are in opposite phases of their motion.

290.
Of nodal lines in general.

What is here said of rods, applies of course to solids of any figure and dimension, neither is there the slightest reason why it should not apply to vibrating masses of air, or any other elastic fluid. Any such mass may be conceived as cut up into two or more oppositely vibrating portions pervading it according to certain laws. Where these surfaces *out-crop* or intersect the external surface of the mass, there will be a *nodal line*.

291.
How such nodal lines are distinguished from each other.

Motions of sand agitated by normal and by tangential vibrations.

Such nodal lines, formed on the surfaces of bodies by the longitudinal vibrations of their molecules, (*i. e.* by vibrations *parallel* to their surfaces,) may be detected and rendered visible to the eye by fine dry sand, or the powder of Lycoperdon, strewed over them; and the motions of the particles in the act of forming them will easily distinguish such vibrations as are executed parallel to the surface (in which, of course, the surface is not thrown into waves) from such as take place at right angles to it, where the surface itself leaps up and down. In the latter case, the particles of sand *dance*, and are violently thrown up and down over the whole extent of the vibrating portions, till, at length, they are entirely dispersed from them. In the former, they only *glide* along close to the surface, and meet and settle on the nodal lines, and that, sometimes, with incredible swiftness. The reason why they retreat to the nodal lines is easily understood. The amplitude of the excursions of the vibrating molecules of the surface diminishes as we approach a nodal line. Hence a particle of sand anywhere situated, if thrown by an advancing vibration *towards* this line, will not be thrown quite so far back by the subsequent retreating vibration, because its *then* situation is one less agitated. Thus the motion of each particle of sand is one of alternate advance towards the node and recess from it, but the advances are always greater than the recesses. In consequence, it *creeps* along the surface, and will not rest till it has attained the node. When a large disc of glass is set vibrating vigorously by a bow, perpendicular to its plane, the grains of sand will fly up some inches from it and be scattered in all directions. M. Savart has distinguished by the name *tangential* vibrations all such motions of the superficial particles of a body as are performed parallel to the surface; while those executed at right angles to it, in virtue of which the surface itself heaves and sinks, he calls *transverse;* and to motions compounded of both these, where the surface both swells and falls and shifts laterally backwards and forwards, he gives the term "*oblique* vibrations." In this we shall follow him.

292.
Longitudinal-tangential vibration of rectangular rods.

Figs. 127, 128.

This acute experimenter has investigated with great minuteness the *tangential* vibrations of long flat rods or rulers of glass, as well as of cylinders and tubes. They are extremely complicated, and offer most singular phenomena, some of which we shall now describe. If we take a rectangular lamina of glass $0^{m}\cdot70$ ($= 27^{in}\cdot56$) long, $0^{m}\cdot015$ ($= 0^{in}\cdot59$) broad, and $0^{m}\cdot0015$ ($= 0^{in}\cdot06$) thick, and holding it by the edges in the middle between the finger and thumb with its flat face horizontal, strewed with sand, and, at the same time, set it in longitudinal vibration, either by rubbing its under side near either end with a bit of wet cloth, by tapping it on the end with light blows, or by rubbing lengthwise a very small cylinder of glass, cemented on to its end in the middle of its breadth, and parallel to its length; in whatever way the vibration be communicated, we shall see the sand on its upper surface arrange itself in parallel lines, at right angles to its longer dimension, *and always, in one or the other of the two systems*, represented in figs. 127 and 128. Now it is very remarkable that although the same one of these two systems will always be produced by the same plate of glass, yet among different plates of the above dimensions, *even though cut from the same sheet, side by side*, one will invariably exhibit one system, and the other the other, without any visible reason for the difference. Moreover, in the system, fig. 127, the disposition of the nodal lines is unsymmetrical, one of them, *a*, being nearer to one end, and the closer pair, *ff*, not being situated in the middle; and this too is peculiar to the plate, for wherever it be rubbed, whichever end be struck, still the line *a* will always be formed nearest to the *same* extremity.

293.
Different arrangement of nodes on the opposite sides.
Figs. 129, 130.

Now let the positions of the nodal lines be marked on the upper surface, and then let the plate be turned till the lower surface becomes the upper, and this being sanded, let the vibrations again be excited just as before. The nodal lines will now be formed quite differently, and will fall on the points just intermediate between those of the other surface; *i. e.* on the points of greatest excursion of its vibrating molecules. In a word, if *n*, *n*, *n*, *n*, &c. in fig. 129, or 130, represent the places of the nodes on the one surface, then will *n'*, *n'*, &c. be those of the other. Thus *all the motions of one half the thickness* of the lamina *are exactly contrary to those of the corresponding points of the other half.* This property, indeed, is general, whatever be the material, length, breadth, or thickness, of the lamina.

294.
Effect of a varied thickness.

If, the other dimensions remaining, the thickness be increased, the *Sound* will remain the *same, but the number of nodal lines will be less.* This fact alone is sufficient to prove an essential difference between the vibrating portions of such a plate, and the ventral segments of an organ-pipe harmonically subdivided.

295.
Tangential vibrations of broad rectangular plates.

If the breadth of a plate of the above length be greater than $0^{in}\cdot6$ the nodal lines cease to be straight, and ranged across the breadth at right angles to the sides. They pass into curves, and, when the breadth is increased to $0^{m}\cdot04$, ($= 1^{in}\cdot57$,) they assume the forms in figs. 131, 132, the former representing the lines on the upper, the latter those on the under surface. If the breadth be enlarged to $0^{m}\cdot06$, ($= 2^{in}\cdot36$,) the figures on the two faces will be as in figs. 133, 134. If the dimensions be so varied as to convert the plate into a square, the nodal figures will assume the forms in figs 135, 136. If the form of the plate pass into the circular or triangular, the same mode of vibration (longitudinal-tangential) being preserved, still the opposite sides of the plates will present different nodal figures, as in figs. 137, 138, and 139, 140.

Of still broader. Fig. 133—140.

296. Longitudinal-tangential vibrations of cylinders.

To examine the longitudinal-tangential vibrations of cylindrical tubes or rods, as sand will not lie on their convex surfaces, M. Savart employed the ingenious artifice used by Sauveur to exhibit the harmonic nodes of a vibrating string. For this purpose the latter set astride on the string a small bit of paper cut into the form of an inverted Λ. But in this case it is found to answer better to encircle the vibrating cylinder with a narrow ring of paper, whose internal diameter is three or four times that of the cylinder, and which, therefore, hangs quite loosely on it. If a cylinder of glass about two metres (6½ feet) long be encircled by several such rings, or *riders*, and, being held horizontally by the middle, as lightly as possible, be rubbed in the direction of its length with a wet cloth, (it should be *very* wet,) it will yield a musical Sound, and all the riders will glide rapidly along it to their nearest nodal points on the upper surface, where they will rest. Now let all these points be marked, and then let the cylinder be turned so as to bring the opposite portion of its circumference uppermost and horizontal, and let the vibration be again excited in the same manner. Then we shall remark the very same phenomenon as in rectangular plates, *viz.* that the nodal points on this edge correspond nearly to the middles of the intervals between those of the opposite one.

297. Nodal lines spirally arranged.

If the cylinder, instead of being turned at once half round, be turned only a little at a time, and always in the same direction, the riders will come to points of rest constantly more and more towards one or the other end of the cylinder, according as it is turned to the right or to the left; and if the *locus* of all the nodal points be traced by this means, it will be found to be a species of spiral line or screw, making one or more turns round the cylinder according to its length.

298. Two spiral nodal lines running opposite ways.

But there exists here a peculiarity bearing an obvious relation to what we have observed already in the case of rectangular plates. The continuity of this spiral is interrupted near the middle of the cylinder, or rather it stops short at a point n, on one side of the central point, and recommences at N, a point equidistant on the other side; *but in a contrary direction*, so as to form on the two moieties of the length of the cylinder a right and a left-handed screw. Again, these spirals are not equally inclined to the axis in all parts of their course. They consist of portions alternately much and little inclined, having points of maximum and minimum inclination alternately at every 90° of their course round the cylinder, as in fig. 141; thus dividing the cylinder into four quadrantal portions, which are related to each other in the same manner as the upper and under faces, and the right and left sides of the vibrating parallelopipeds, examined in Arts. 292. *et seq.*

Fig. 141.

299. Four principal edges of a vibrating cylinder.

It appears then that when a cylinder is set in a state of longitudinal-tangential vibration, it assumes of itself (by reason no doubt of some casual inequality in its form or structure, giving it a bias one way or the other) four principal edges, dividing it into quadrantal portions. Of these, two opposite ones (which we will designate by the numbers 1 and 3, and call the upper and under edge) are divided by the nodal lines in points n_1 n'_1 N_1 N'_1, and n_3 n'_3 N_3 N'_3, where their inclination is a maximum, and the others 2, 4, which we may call the sides, at n_2 n'_2 N_2 N'_2, and n_4 n'_4 N_4 N'_4, where it is a minimum.

300. Nodal lines in the interior of a cylindrical tube.

What we have said relates to the disposition of the nodal lines on the exterior surface of a tube, or of a solid cylinder. In the case of a hollow tube, the nodal lines of the internal surface may be examined by strewing in it a little fine sand, provided its diameter be so large as not to drive all the sand into a crowded line along the bottom. We shall thus detect a spiral in all respects similar to that on the external surface; only that its coils run exactly along the intervals of those of the external one. So that in all cases, those points of the internal surface are most strongly agitated by the vibration which correspond to points at rest on the outer, and *vice versâ*. M. Savart has noticed a very curius phenomenon in this case. At the points of maximum inclination the sand gathers itself up in a circular heap, and remains at perfect rest; but at those of minimum inclination it forms a long ellipse, the borders of which keep constantly circulating in one direction; and if instead of sand, a small globe of ivory or wax be put into the tube; at these points it remains, it is true, without shifting its *place*, but spins constantly in one direction round a vertical axis, so long as the vibration continues.

301. Higher modes of vibration and subdivision of the cylinder into ventral segments.

We have all along supposed that the state of vibration into which the cylinder or tube is thrown, is that corresponding to the gravest tone it can yield by vibrations of the kind in question. M. Savart has examined its higher modes, and has pointed out other peculiarities, but for these we must refer the reader to his Memoir, *Ann. de Chim.* vol. xxv. p. 236. We will merely remark that in these modes, the threads of the screw break off, and reverse their direction at the points of union of the several ventral segments.

§ II. *Of the Communication of Vibrations from one Vibrating Body to another.*

302. General law of the communication of vibratory motion.

We have already seen that a rod placed between two discs, one of which is set in vibration, becomes the means of communicating its vibrations to the other. But it may be announced as a general fact, that whenever a vibrating body is brought into intimate contact with another, it communicates to it its own vibrations, more or less effectually as their union is more perfect. This proposition has been carried still further by M. Savart, whose experiments show that all the particles of the body thus set in vibration by communication are agitated by motions not merely similar in their periods, but actually parallel in their directions, to those of the original source of the motion. Examples will best explain the meaning of this.

303. Fig. 142. Vibrations of a flat rod communicated from a bell-glass.

Example 1. Let A, fig. 142, be a long flat glass ruler or rod, cemented with mastic to the edge of a large bell-glass, such as is used for the *harmonica*, or musical glasses, or a large hemispherical drinking-glass, perpendicular to its circumference. Let it be very lightly supported in a horizontal position on a bit of cork at C, and then let the bell-glass be set in vibration by a bow, at a point opposite the place where the rod meets it. It will vibrate *transversely*, *i. e.* the motions of its molecules will be perpendicular to its surface; and these motions will be communicated to the rod, without any change in their direction, whose vibrations will be longitudinal-tangential, as will be rendered evident by strewing its surface with sand, when the nodal lines will be formed as in Art 292, and, if the apparatus be inverted, and the sand strewed on the under side of the rod, the nodal lines will be seen to correspond to the points of greatest excursion on the other side, as in that article.

304. Vibrate together as a system.

In this combination the original tone of the bell-glass is altered, and the note produced differs both from that yielded by it, or by the glass rod vibrating alone. The two vibrate as a system together and, what is singular, the Sound of the glass is considerably reinforced by the combination.

305. Fig. 143. Joint vibrations of two rods transverse to each other.

Example 2. Let A′ be a rectangular strip of glass firmly cemented at right angles to another strip, A, across its breadth. Let the latter be lightly supported on two bits of cork, C, fastened to a wooden piece, B, so as just to touch A in the places of two of its nodes when vibrating transversely. Then, if A be placed horizontally, and strewed with sand, and A′ be set in longitudinal-tangential vibration, either by rubbing with a wet cloth, or by any other means, A will vibrate transversely, as will be known by the dancing of the sand and its settling on the nodes C C′. On the other hand, if A be held vertically, and agitated transversely by a bow, while A′ is horizontal and strewed with sand, the latter will indicate longitudinal-tangential vibrations, both by the creeping of the sand, and by the difference of the nodal figures on its two faces.

306. Fig. 144. Joint vibrations of a system of discs and rods.

Example 3. Let M be a rectangular plate (fig. 144) mounted like A in the last example, but instead of carrying a simple plate A′, let it carry a system of circular discs traversed by a lamina, as in the figure. Then, if the faces of these discs and of the lamina M be horizontally placed and strewed with sand, and the lamina M be set in longitudinal-tangential vibration, all the discs will be so too, and the sand will arrange itself in figures which, on every alternate disc, 1, 3, 5, &c. will be of one species, (such as at *a* for instance,) but on every other, 2, 4, 6, &c. will be of a different species, as *b*. Now if the whole apparatus be inverted, so as to place the lamina M uppermost, and let the system of discs hang down, the *then* upper surfaces of the discs will exhibit the same system of nodal figures, but in the reverse order: *i. e.* the discs 1, 3, 5, &c. will give the figure *b*, and 2, 4, 6, &c. the figure *a*. In this apparatus, if the connecting piece which traverses all the discs be examined, it will be found to vibrate *transversely*, while the discs and lamina M vibrate tangentially, and *vice versâ*.

307. Fig. 145. Vibrations of a disc excited by communication from a string.

Example 4. Let A be a strong frame of wood of the form [, across the extreme edges of which is stretched a strong catgut or other chord, and let L L′ be a circular disc of glass, or metal, retained between the chord and back of the frame by the pressure of the former. Then, if the chord be set in vibration by a bow drawn transversely across it in one steady direction, the vibrations of the chord will all lie in the plane of the bow, and will be communicated in *the same* direction to the disc, which will execute tangential vibrations, each of its molecules moving to and fro in lines parallel to the bow *through the whole extent of the disc.* This is easily verified by the direction in which sand strewed on it creeps. Conceive the whole apparatus placed with the chord vertical, and projected on the plane of the horizon. If, as in fig. 145, *a*, F F′ be the projection of the bow, the surface of the disc will be marked with nodal lines parallel to it, the sand there being left, while that in the intermediate spaces creeps along to the edges, as marked by the arrows, and runs off. If the projection of the bow F F′ be oblique to the line joining the points of support of the disc, as in fig. 145, *c*, the nodal line will be curved, as there shown, but the motion of the molecules of sand going to form it will still be parallel to F F′. Finally, if the bow be drawn parallel to the line joining the points of support, as in fig. 145, *d*, the nodal line will be formed of two arcs making a cusp, but the same law of molecular motion will still hold good, as the arrows indicate.

308. Fig. 146. Passage of oblique vibrations into tangential, or into transverse. Fig. 147—150.

Example 5. Let L L′ be a rectangular lamina fastened at one end into a block, T, and at the other attached to a chord, *c e*, stretched parallel to its length, over a bridge, *e*, and put in vibration by a bow perpendicular to it, F F′. Then, if the plane of the bow and string coincide with the plane of the surface of the lamina, the latter will execute tangential vibrations *across* its breadth, and will exhibit on its upper surface a single nodal line, *n n′ n″*, as in fig. 147, but on its under none, all the sand being driven off. Now incline the bow to the surface of the lamina as represented in fig. 146, *c*, at an angle of about 20°, still keeping it perpendicular to the string, and the nodal line will assume the curvature represented in fig. 148. If the bow be still more inclined, the curve breaks up, and at 45° of inclination becomes changed into transverse and oblique lines, as in fig. 149; and it is now observed that the sand not only runs in the direction of the arrows, but also begins to leap, indicating an oblique vibration of the surface. Lastly, when the bow is inclined 90° to the plane of the lamina, as in fig. 150, the vibration becomes altogether transverse, the nodal lines are similarly disposed on both sides of the plate, and the sand merely leaps up and down till it is danced off the vibrating parts, without any tendency to creep.

309. Vibrations of a membrane excited by communication from the air. Case I. Transverse vibrations.

Example 6. If a very thin membrane be stretched horizontally over the orifice of a circular bowl, as a drinking-cup, or *harmonica-glass*, (extremely thin paper wetted and glued to the edges, and then suffered to become tight by drying, answers very well,) and if fine sand be strewed on it, it becomes a most delicate detector of aerial vibrations. Suppose now a circular disc of glass held concentrically over it with its plane parallel to that of the membrane, and set in transverse vibration so as to form any of Chladni's acoustic figures, as for instance fig. (99). Then will this figure be imitated exactly by the sand on the membrane. Now let the vibrating disc be shifted laterally, so as no longer to have its centre vertically over that of the membrane, but keeping its plane, as well as that of the membrane, horizontal. Still the figures marked out on the latter will be fac-similes of those on the disc, and that, whatever be the extent of lateral removal, till the vibrations become too much enfeebled by distance to have any effect at all.

310. Oblique vibrations. Tangential.

But, in place of shifting the disc laterally, let its plane be inclined to the horizon. Immediately the figures on the membrane will change though the vibrations of the disc remain unaltered, and the change will be the greater, the greater be the inclination of the plane of the disc to that of the membrane. And when the former plane is perpendicular to the horizon, the nodal figure on the membrane is found to be transformed into a system of straight lines parallel to the common intersection of the two planes, and the particles of sand instead of dancing, creep in opposite directions to meet in these lines. One of these always passes through the centre, and the whole system is analogous to what would be produced by attaching a cord to the centre of a disc, and, having stretched it very obliquely, setting it in vibration by a bow drawn parallel to the surface. In a word, the vibrations of the membrane are now tangential, and they preserve this character unchanged, however the disc be *now* shifted laterally, provided its plane be not turned from the vertical position. If the disc be made to revolve about its vertical diameter, the nodal lines on the membrane will rotate, following exactly the motion of the disc.

311. Nature of the aerial motions in a Sound-wave.

Nothing can be more decisive or instructive than this experiment. We here see evidently, that the motions of the aerial molecules in every part of a spherical wave, propagated from a vibrating body as a centre, instead of diverging like radii in all directions so as to be always perpendicular to the surface of the wave, are all parallel to each other; in a word, they are disposed, not as in fig. 8, but as in fig. 7; and thus the hypothesis of Art. 118. is found to be completely verified. And the same thing holds good not only in air, but in liquids, as the experiments hereafter to be related (due, like all those just cited, to M. Savart) satisfactorily demonstrate.

312. Data on which the vibrations of a membrane depend.

This experiment is also remarkable in several other points of view. So long as the Sound of the disc, and its mode of vibration, as well as its inclination to the plane of the membrane, and the tension of the latter, continue unchanged, the nodal figure on the membrane will continue the same; but if either of these be varied, the membrane will not cease to vibrate, but the figure will be modified accordingly. Let us consider separately the effect of each of these changes.

313. First, the pitch of the Sound.

And first, *cæteris immutatis*, let the *pitch* of the Sound whose vibrations, communicated through the air to the membrane, excite its motions, be altered, as by loading the disc, or increasing or diminishing its size, (or, if the Sound be excited by any other cause, as a pipe, the voice, &c., then by varying its pitch by any appropriate means.) The membrane will still vibrate, *differing in this respect from a rigid lamina*, which will only vibrate by sympathy with Sounds corresponding to its own subdivisions. The *membrane*, be it observed, will vibrate in sympathy with *any* Sound, but every particular Sound will mark out on it its own particular nodal figure, and as the pitch varies the figure varies. Thus if a slow air be played on a flute near it, each note will call up a particular form, which the next will efface, to establish its own.

314. Secondly, the nature and mode of vibration of the exciting cause.

Secondly. Suppose the exciting cause be the vibration of a disc, or lamina of any form. If its mode of vibration be varied so as to change its nodal figures, those on the membrane will vary; and if the *same note* be produced by different subdivisions of different sized discs, the nodal figures on the membrane will be different.

315. Thirdly, the tension of the membrane. Effect of hygrometric changes on paper membranes.

Again, if the tension of the membrane be varied ever so little, most material changes will take place in the figures it exhibits. If paper be the substance employed, mere hygrometric changes affect it to such a degree, that if moistened by breathing on it, and allowed to dry while the exciting Sound is continued, the nodal forms will be in a constant state of fluctuation, and will not acquire permanence till the paper is so far dried as the state of the surrounding atmosphere will permit. Indeed, this fluctuation is so troublesome in experiments of this kind, that to avoid them it is necessary to coat the upper or exposed side of the paper with a thin film of varnish. Of all substances which can be employed for the exhibition of these beautiful experiments, M. Savart observes, by far the best is such a varnished paper stretched on a frame and moistened on the under side. The moisture diminishes the cohesion of the fibres, and renders them nearly independent of each other, and indifferent to all impulses. As a proof of this, he observes, that he has frequently obtained, on a circular membrane of paper so prepared, a nodal figure composed of no fewer than twenty concentric annuli, which is far beyond what can be obtained in any other way.

316. Secondary nodal figures.

In some cases, a very curious and instructive phenomenon is observed in these experiments. Between the nodal lines formed by the coarser and middle-sized grains of sand, others will be occasionally observed, formed only of the very finest dust, of microscopic dimensions. This phenomenon will be seen to greater advantage if a little dust of Lycoperdon be mixed with the sand. These intermediate lines M. Savart explains, by referring them to different and higher modes of subdivision, coexisting with that by which the principal figure is formed. The more minute particles are proportionally more resisted by the air than the coarser ones, and are thus prevented from making those great leaps which throw the coarser ones into their nodal arrangement. They, therefore, rise and fall with the surface, to which they are as it were pinned down. But they are affected by the minuter waves which have a smaller amplitude of excursion, and occur more frequently, and form their figures under the influence of these as if the greater ones did not exist. These *secondary figures* often appear as concentric rings between the primary ones, and not unfrequently the centre of the whole system is occupied by a secondary point.

317. Fig. 151—166.

Figures 151—161 are specimens of the nodal figures thus formed on circular membranes. Of these, fig. 161 shows the modification which is apt to take place when the tension of the membrane is not quite equable. Figs. 162, 163, are figures exhibited by square membranes, and fig. 164—166 by triangular ones.

318. Stretched membranes employed to detect sonorous vibrations.

A very important application of these properties of stretched membranes has been made by M. Savart, by employing such a one as an instrument for detecting the existence and exploring the extent and limits of contiguous and oppositely vibrating portions of masses of air. For, since such a membrane is thrown into vibration by all aerial vibrations of a certain force, the fact of the existence or not of a vibratory motion in any point of the air, of a chamber for instance, or a box, or large organ-pipe, may be ascertained by observing whether sand strewed on it is set in motion, and arranged in regular forms, on holding the membrane at that point. Thus if an organ-pipe be made to sound with a constant force, and the *exploring membrane* be so far removed from it that the membrane shall just cease to be agitated visibly, the force of the Sound being increased by a quantity not sensible to the ear, the sand will recommence its motion. Nay, if two such pipes, placed close together, be made to *beat*, (see Index, *Beats*,) the membrane will be seen to be agitated at the coincidences, and at rest in the interferences of their vibrations. We shall presently return to this part of our subject.

319. Use of the membrana tympani.

Another highly interesting application of the same properties, is the view which M. Savart has taken of the use of the "membrana tympani" in the ear. Of all our organs, perhaps, the ear is one of the least understood. It is not with it as with the eye, where the known properties of light afford a complete elucidation of the whole mechanism of vision, and the use of every part of the visual apparatus. In the ear every thing is on the contrary obscure; anatomists, it is true, have scrupulously examined its construction, and many theories have been advanced of the mode in which Sounds are conveyed by it to the auditory nerve, (where of course, as with the optic nerve in the eye, all inquiry terminates, for to trace the progress of sensation along the nerve to the brain, and thence to the sentient soul, it is needless to remark, is altogether beyond our reach.) But nothing certain can be said to be known, though it is to M. Savart that we owe the most rational hypotheses hitherto proposed.

320. Fig. 167. Construction of the ear. Fig. 168.

Fig. 167 represents the auditory apparatus. It consists externally of a wide, conch-shaped opening, K L, which contracts into a narrow pipe, A B, defended from the entry of dust and insects by hairs, and a viscous exudation which is slowly secreted, and terminated by a thin elastic membrane, called the ***Tympanum***, F, or drum of the ear. Behind this there is a cavity which communicates with the mouth by a small duct called the Eustachian tube, H G I. If this be stopped, deafness is said to ensue, but, as Dr. Wollaston has shown, only to Sounds within certain limits of pitch. In the cavity behind the tympanum is placed a mysterious and complicated apparatus, B C P S, represented complete, and on an enlarged scale, in fig. 168, consisting of four little bones, of which the first, S C, is called the hammer, and rests with its smaller end in contact with the tympanum, and its larger on the second bone, B P, called the *anvil*, between which, and the last, V, called the ***stirrup***, a little round bone, P, forms a communication. These bones form a kind of chain, and no doubt vibrations excited in the tympanum by vibrating air, as in the experiments above detailed, are somehow or other propagated forward through these; but they are so far from being essential to hearing, that when the tympanum is destroyed, and the chain in consequence hangs loose, deafness does not follow. The last of this chain of bones, however, is attached to another membrane, *p*, which closes the orifice of a very extraordinary system of canals, excavated in the bony substance of the skull, called the *Labyrinth*, represented separately in fig. 169, which consists of three semicircular arcs, (1, 2, 3,) originating and terminating in a common canal, which is prolonged into a spiral cavity (4) called the cochlea. The whole cavity of the labyrinth is filled with a liquid, in which are immersed the branches of the auditory nerve, in which, no doubt, resides the immediate seat of the first impression of Sound, as that of sight does in the retina. If the membrane which closes the labyrinth be pierced, and this liquid let out, complete and irremediable deafness ensues. It appears from some most extraordinary experiments by M. Flourens on the ears of birds, (of which, however, the details are too revolting to find a place in any but works on anatomy and physiology,) that the nerves enclosed in the several canals of the labyrinth, have other uses besides their services as organs of hearing, and serve, in some unaccountable and mysterious manner, to give to animals their faculty of balancing themselves on their feet, and directing their motions. On this point we refer the reader to M. Cuvier's report on M. Flourens's Memoir, *Annales de Chimie*, vol. xxxix. p. 104, and of course to the Memoir itself, whenever and wherever it may appear; and for other not less interesting and extraordinary facts of a similar nature, to M. Majendie's Paper on the functions of the two great divisions of the spinal column, and the influence of the cerebrum and cerebellum on voluntary motion, abstracted by himself in a late volume of that collection.*

321. Vibrations of an unelastic membrane how produced. Fig. 170.

To understand how the vibrations of a disc may be conceived to be communicated by the air to a membrane in M. Savart's experiments, let us take a simple case, and suppose A B C D to be a horizontal circular disc, vibrating in that mode which gives a subdivision into four quadrantal segments, A C, C B, B D, D A; and let *a b c d* be an infinitely thin circular membrane placed under it, which we will suppose to be ***barely coherent*** so as to be impervious to air, but to have *no tension* of its own. Its molecules will, therefore, obey implicitly all the motions of the aerial ones adjacent to them, and its figure, at any instant, will be that assumed by a stratum of the air originally plane, and parallel to A B C D, in consequence of the displacement of its particles by the undulation propagated from all parts of A B C D, as they reach it *at once*, allowing for the time taken to traverse their respective distances from it. Let us now consider how a molecule of air, M, placed any where in the plane $a\,e\,\beta$ perpendicular to the disc, and intersecting it in A B, will be affected. Since the disc vibrates transversely, all its particles on one side of A B (as towards C) will be at any instant in a precisely opposite *phase* of their excursion from the corresponding particle on the side towards D, and moving with equal velocity. Therefore, the undulations propagated simultaneously from both these particles will reach the molecule M in question at once, (being equidistant from it,) and being (at least in so far as their direction is not modified in their passage, and at all events as to that part of them which is at right angles to the plane $a\,\beta\,\gamma\,\delta$) equal, and contrary, destroy each other, so that in virtue of these the molecule M acquires no transversal vibration. And since the same is true of every other corresponding pair of molecules into which the two halves A C B and A D B of the vibrating disc can be divided, the molecule M will not vibrate (or at least not transversely) in virtue of the vibration of the whole disc. The same is true of every other molecule situated in the plane $a\,e\,\beta$, and also by a similar reasoning in the plane $\gamma\,e\,\delta$ at right angles to it. There will then be two *nodal planes* pervading the whole atmosphere, in which the aerial molecules have no transverse (*i. e.* vertical) motion. But if we suppose the molecule M situated any where out of these planes the case is otherwise. Suppose it, for instance, situated at *f*, in the quadrant *c e b* of the membrane. This being nearer to each molecule of the quadrant C E B of the disc than to the corresponding molecules of the others, the influence of the former will predominate, and the molecule *f* will be agitated by a transverse motion similar to that of the quadrant of the disc vertically over it. If then the membrane be strewed with sand, it will be thrown off from the vibrating quadrants, and arranged on two rectangular nodal lines *a b*, *c d* parallel to those of the disc, just *as if* it vibrated by its own tension, while yet it is obvious that all the while it has only obeyed implicitly the motions of the adjacent air.

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* From the painful subject of knowledge of the most interesting and practically useful kind, to be purchased only by the extremity of animal suffering, we turn with gladness to a pleasing duty. We have drawn largely, both in the present Essay, and in our Article on LIGHT, from the *Annales de Chimie*, and we take this *only* opportunity distinctly to acknowledge our obligations to that most admirably conducted work. Unlike the crude and undigested scientific matter which suffices (we are ashamed to say it) for the monthly and quarterly amusement of our own countrymen, whatever is admitted into *its* pages has at least been taken pains with, and, with few exceptions, has sterling merit. Indeed, among the original communications which abound in it, there are few which would misbecome the first academical collections; and if any thing could diminish our regret at the long suppression of those noble Memoirs which are destined to adorn future volumes of that of the Institute, it would be the masterly abstracts of them which from time to time appear in the *Annales*, either from the hands of the authors, or from the reports rendered by the committees appointed to examine them, which latter, indeed, are universally models of their kind, and have contributed, perhaps more than any thing, to the high scientific tone of the French *savans*. What author, indeed, but will write his best when he knows that his work, if it have merit, will immediately be reported on by a committee who will enter into all its meaning, understand it however profound, and not content with *merely* understanding it, pursue the trains of thought to which it leads, place its discoveries and principles in new and unexpected lights, and bring the whole of their knowledge of collateral subjects to bear upon it. Nor ought we to omit our acknowledgments to the very valuable Journals of Poggendorff and Schweigger. Less exclusively national than their Gallic compeer, they present a picture of the actual progress of Physical Science throughout Europe. Indeed, we have been often astonished to see with what celerity every thing, even moderately valuable in the scientific publications of this country, finds its way into their pages. This ought to encourage our men of science. They have a larger audience, and a wider sympathy than they are, perhaps, aware of; and however disheartening the general diffusion of smatterings of a number of subjects, and the almost equally general indifference to profound knowledge in any, among their own countrymen, may be, they may rest assured that not a fact they may discover, nor a good experiment they may make, but is instantly repeated, verified, and commented upon, in Germany, and we may add too in Italy. We wish the obligation were mutual. Here, whole branches of continental discovery are unstudied, and indeed almost unknown even by name. It is in vain to conceal the melancholy truth. We are fast dropping behind. In Mathematics we have long since drawn the rein and given over a hopeless race. In Chemistry the case is not much better. Who can tell us any thing of the Sulfo-salts? Who will explain to us the laws of Isomorphism? Nay, who among us has even verified Thenard's experiments on the oxygenated Acids—Oersted's and Berzelius's on the radicals of the Earths—Balard's and Serrulas's on the combinations of Brome—and a hundred other splendid trains of research in that fascinating science? Nor need we stop here. There are, indeed, few sciences which would not furnish matter for similar remark. The causes are at once obvious and deep seated. But this is not the place to discuss them.

322. **Effects of tension and thickness of the membrane.** If, however, the membrane has tension and thickness, this will modify the effects of the direct aerial action, and that in a way far too complicated for us to enter into here in detail. We may remark, however, that in that case, each individual aerial impulse must be regarded as an arbitrary initial disturbance of its state of equilibrium, in virtue of which it will be thrown into periodic vibrations; and these again will propagate similar vibrations back through the air to the disc A B C D; and this being constantly repeated the result *may* be the establishment of a joint resultant periodic vibration, by the destruction of every motion not periodic, from the innumerable repetitions of the impulses and the consequent infinite superposition of plus and minus excursions. But this interchange, of course, will be the more energetic the thinner is the interposed lamina of air; for if its thickness be great, the vibrations excited in the membrane, or semi-rigid disc, *a b c d*, (as we will now suppose it,) will be feeble, and when propagated back through the air will be still further enfeebled so as to affect the motion of A B C D but little. In this case then, supposing the two discs to be out of unison with each other, and to have no common mode of vibration, the disc *a b c d* will become the seat of two distinct systems of vibration. The first, regularly periodical, being that directly communicated by sympathy. The other, the resultant of an indefinite number of vibrations kept up by means of the tension, in all phases and stages of degradation.

323. **General theorem respecting forced vibrations.** Now, provided the time elapsed since the commencement of the vibrations be long enough to allow of our regarding the number of previous vibrations as infinite, or which comes to the same, long enough to have allowed all traces of the initial vibrations to have been destroyed by resistance, friction, &c., these last will either exactly destroy each other, or, if they leave a residue, that residue will consist in a vibratory motion, having the same period with the primary impulse.

324. **Demonstration.** As this is a proposition of great importance, not only in the theory of Sound, but in many other physical theories, such as that of the Tides, for example, we must not let it rest on a vague assumption, but demonstrate it rigorously. Let then t represent the time elapsed since the commencement of the vibrations, t being so large that it may be considered as infinite in comparison of the duration of a single vibration. Then if we call T the time of one complete vibration, or one period of the primary vibrations, the impulse communicated through the air, or otherwise, to any point of the membrane, or other vibrating body, will at any instant be represented by some periodic function of the form $\mathrm{F}\left(\cos 2\,\pi\,.\,\dfrac{t}{\mathrm{T}}\right)$, or $\mathrm{F}\,(\cos n\,t)$ putting $\dfrac{2\,\pi}{\mathrm{T}} = n$, which function may always be resolved into a series of periodical terms of the form $\mathrm{A}\,.\,\cos i\,n\,t$, i being an integer, of which each may be considered as the representative of a single vibratory motion of the simplest kind, whose superposition forms the actual vibration in question. Consequently, we may content ourselves with considering any one of them as $\mathrm{A}\,.\,\cos n\,t$, since all the rest are subject to the same argument.

325. Next, let θ be the time of one complete unforced vibration of the membrane or elastic body in virtue of its natural elasticity, and let $\nu = \dfrac{2\,\pi}{\theta}\,.\,i$, so that $a\,.\,\cos \nu\,t$ would denote the general term of a series expressing the velocity of any one of its molecules in a state of unforced vibration, and let $\mathrm{F}\,(t)$ be a function expressive of the law of diminution of the vibrating motion by friction, resistance, and imperfect elasticity. So that if t be the time since a certain velocity V was communicated to it, $\mathrm{V}\,.\,\mathrm{F}\,(t)\,.\,\cos \nu\,t$ will be its velocity after the expiration of t as it will then subsist, modified by the elastic forces and mechanical state of the membrane.

326. Conceive the aerial impulse to act not continuously, but at equal infinitely small intervals of time τ, (infinitely small relative not only to t but to T and θ.) Then, first, the impulse $\mathrm{A}\,.\,\cos n\,t$, acting during the time τ, will produce the velocity $\mathrm{A}\,.\,\tau\,.\,\cos n\,t$.

Secondly. The impulse $A \cdot \cos(nt - n\tau)$ which acted at the moment immediately preceding, produced in the first instance the velocity $A \cdot \tau \cdot \cos(nt - n\tau)$. But this, once produced, was immediately modified by the inherent elasticity of the membrane, and in the subsequent moment became

$$A \cdot \tau \cdot \cos n(t - \tau) \cdot F(\tau) \cdot \cos \nu\tau.$$

Similarly the impulse $A \cdot \cos n(t - 2\tau)$ acting at the instant preceding *this* generated the velocity $A\tau \cdot \cos(t - 2\tau)$, which, in like manner, (being regarded as an arbitrary initial disturbance,) became modified in the time 2τ to $A\tau \quad \cos n(t - 2\tau) \cdot F(2\tau) \cdot \cos 2\nu t$. And so on. Thus, the whole accumulated velocity at the instant t, arising from *all* the preceding impulses, will be expressed by

$$A\tau \cdot \{\cos nt + \cos n(t - \tau) \cdot \cos \nu\tau \cdot F(\tau) + \cos n(t - 2\tau) \cdot \cos 2\nu\tau \cdot F(2\tau) + \&c.\},$$

which series, since the function expressed by $F(t)$ is supposed to decrease constantly as t increases, and since the whole number of vibrations is supposed so great that the terms of the series $F(t)$, $F(2\tau)$, $F(3\tau)$, &c. shall at length become perfectly insensible, may be regarded as continued *ad infinitum*.

327. General law of slow decay of vibratory motion in geometric progression.

In fact, whatever supposition we may make as to the law of degradation of the motion within the limit of a single period, it must evidently diminish in geometrical progression in similar phases of successive periods, so that we must have

$$F(\tau + \theta) = q \cdot F(\tau); \; F(\tau + 2\theta) = q^2 \cdot F(\tau) \; \&c.$$

This premised, the series in question, by merely changing the arrangement of its terms, and grouping together those equidistant from each other by the interval θ, will become resolved into partial series thus,

$$A\tau \cdot \left\{\begin{array}{l} \cos nt + \cos n(t - \theta) \cdot \cos \nu\theta \cdot F(\theta) + \cos n(t - 2\theta) \cdot \cos 2\nu\theta \cdot F(2\theta) + \&c. \\ + \cos n(t - \tau) \cdot F(\tau) + \cos n(t - \tau - \theta) \cdot \cos(\nu\theta + \nu\tau) \cdot F(\theta + \tau) + \&c. \\ + \&c. \end{array}\right\}$$

But we have, first, $F(o) = 1$, $F(\theta) = q$, $F(2\theta) = q^2$, &c.; and, moreover, since $\nu\theta = 2i\pi$, therefore $\cos \nu\theta = 1$, and $\cos 2\nu\theta = 1$, &c. Consequently the above expression becomes

$$A\tau \left\{\begin{array}{l} (\cos nt + q \cdot \cos n(t - \theta) + q^2 \cdot \cos n(t - 2\theta) + \&c.) \\ + F(\tau) \cdot (\cos n(t - \tau) + q \cdot \cos n(t - \tau - \theta) + q^2 . \&c.) \\ + F(2\tau) \cdot (\cos n(t - 2\tau) + q \cdot \cos n(t - 2\tau - \theta) + q^2 . \&c. + \&c.) \end{array}\right\}.$$

Summation of the partial series.

Now, each of these series is readily summed, for we have by well-known trigonometrical formulæ

$$\cos nt + q \cdot \cos(nt - n\theta) + q^2 \cdot \cos(nt - 2n\theta) + \&c.$$

$$= \cos nt \cdot \frac{1 - q \cdot \cos n\theta}{1 - 2q \cdot \cos n\theta + q^2} + \sin nt \cdot \frac{q \cdot \sin n\theta}{1 - 2q \cdot \cos n\theta + q^2}.$$

Each of the fractions being constant, and independent of t, if we call them M and N, our series will become

$$A\tau \cdot \left\{\begin{array}{l} (M \cdot \cos nt + N \cdot \sin nt) + F(\tau)\{M \cdot \cos n(t - \tau) + N \cdot \sin n(t - \tau)\} \\ \qquad + F(2\tau)\{M \cdot \cos n(t - 2\tau) + N \cdot \sin n(t - 2\tau)\} \\ \qquad + \&c. \end{array}\right\}.$$

328. Summation of the whole by a definite integral.

Let us now consider the area of a curve whose abscissa, x, is divided into equal elements each equal to τ, while its successive ordinates, y, are represented by $\phi(o)$, $\phi(\tau)$, $\phi(2\tau)$, &c. It is evident that its area $\int y\,dx$ will be equal to

$$\tau \cdot \phi(o) + \tau \cdot \phi(\tau) + \tau \cdot \phi(2\tau) + \&c.;$$

and, therefore, the sum of this series, from the term $\tau \cdot \phi(o)$ to $\tau \cdot \phi(\theta)$, will be equal to the integral $\int \phi(x)\,dx$, from $x = 0$ to $x = \theta$. Thus our series will assume the form of a definite integral, *viz.*

$$A \cdot \int_0^\theta dx \cdot F(x)\{M \cdot \cos n(t - x) + N \cdot \sin n(t - x)\},$$

expressing in the manner now pretty general the limits of the integral by indices attached to the integral sign. Resolving now the sines and cosines of $n(t - x)$, this becomes (x and t being independent of each other)

$$A \cdot \cos nt \cdot \int_0^\theta dx \cdot F(x)\{M \cdot \cos nx - N \cdot \sin nx\}$$
$$- A \cdot \sin nt \int_0^\theta dx \cdot F(x)\{M \cdot \sin nx - N \cdot \cos nx\}.$$

Now, whatever be the law of degradation denoted by the function F, it is clear that these definite integrals must at last reduce themselves to certain constants independent of t, which, if we call P and Q, the whole takes the simple form

$$P \cdot \cos nt - Q \cdot \sin nt,$$

which is a periodic function having the same period as the primary vibrations.*

329. Case of perfect elasticity of the excited body.

In the limiting case, when the elasticity of the body on which the forced vibrations are impressed is perfect, and resistance, friction, and every other cause of loss of motion is prevented, F represents a constant, and is equal to unity. In this case both the constants P and Q in the above expressions vanish, and the whole motion of the body, after a great number of vibrations have elapsed, is zero. In this case then, the elastic body is completely incapable of vibrating in sympathy with any other not having a common mode. In all others, P and Q have finite values, which will be greater, or less, according to the circumstances of the case.

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* This demonstration being general, we may here observe, that, on the undulatory theory of light, rays of one refrangibility can never excite by any combination of their own vibrations with those of the bodies they may traverse or impinge on, any resultant rays of a different refrangibility, at least so long as the exciting light continues in action When it has ceased, the case may be otherwise.

330. General effect of imperfect elasticity.

Thus we see that imperfect elasticity, or other equivalent causes of the gradual loss and dissipation of the impressed impulses, is the essential condition on which forced vibrations in general depend, and that in proportion as a disc or membrane is devoid of tension it should be more readily susceptible of such vibrations: precisely what M. Savart has shown to be really the case in fact.

331. Objections considered.

It may be objected to what is said in Art. 321, that it would follow from that reasoning that the Sound of a vibrating disc should be inaudible whenever the ear is situated in a plane passing through one of its nodal diameters, and at right angles to the disc. But, in the first place, what is there said applies only to such motions of the aerial particles as are performed in those planes. But, in fact, a lateral motion, or one parallel to the disc's surface, must also exist, by reason of the alternate *tilting* up and down of adjacent ventral segments, which must give the whole body of air terminated by them a small reciprocating rotatory motion about the nodal line separating them as an axis. Thus, though the transverse vibrations are here destroyed, the sensation of Sound may still be excited by tangential ones. And, secondly, though alternate motion were altogether destroyed, condensations and rarefactions still subsist.

332. Phenomena of a tuning-fork explained. Fig. 171.

But, in fact, there *is* observed a difference in the intensity of Sound emanating from vibrating bodies in certain cases, according to their angular position with respect to the line joining them and the ear. We have already (Art. 117.) described Dr. Young's remarkable experiment of the tuning-fork. It is precisely a case in point, and a circumstantial explanation of it will be at once interesting for its own sake, and illustrative of the general argument. Let then A, B, fig. 171, be sections of the two branches of the fork in its state of rest, and since when set in vibration they alternately approach to and recede from each other, let us consider them first in their state of approach, as at $a\,b$. In this state they compress the air between them, and squeeze it out laterally in the direction of the arrows P, Q, while, at the same instant, the aerial particles adjacent to the flat outward faces of the two branches, and which of necessity follow their motions, are urged inwards as indicated by the arrows R S. Thus the four quadrants of the initial circular wave propagated round the fork, are alternately in opposite states of motion, the molecules at P Q receding from the centre, while those at R, S, approach to it, and *vice versâ*, when the branches of the fork having closed to the utmost begin to open again. In this case the lateral air will rush in to fill the gap, while that in contact with the broad faces will be forced outwards. If then we consider any intermediate point C, about 45° distant from Q and R, this, in virtue of both impulses, will acquire equal tendencies in opposite directions, and will rest, or at least will acquire only a small tangential motion, in consequence of the reciprocating eddies of the air round the angles of the branches. That these motions really do take place as here pointed out, any one may have ocular demonstration by imitating the opening and shutting of the branches with his hands near the flame of a candle burning steadily, taking care not to make *puffs* of *wind* but regular removals of the air to and fro.

333. Membranes used to explore the vibrations of masses of air. Intense Sounds produced by resonance.

One of the most curious and interesting purposes to which M. Savart has applied the properties of membranes, is to explore the actual state of the air in different parts of a vibrating mass of determinate figure, as to motion or rest. For this purpose, the Sound should be excited and maintained by a constant cause at a high degree of intensity, especially if the mass of air be large, as in a chamber or gallery; and to give the membrane the greatest possible sensibility, it ought to be stretched so as to be, naturally, in unison with the note sounded, so as to act as a receiver and condenser of the small aerial motions. The greatest purity and intensity of the Sounds to be employed for this purpose, may be obtained by a *harmonica* glass, or the bell of a clock, maintained in vibration by a bow; and this may be still further augmented by adapting to it a resonant cavity, as, for instance, a large cylindrical vase of considerable diameter, closed at one end, and of such dimensions as separately to vibrate the same note. (See Art. 338.) The tones thus produced, especially when large *harmonica* glasses are used, as M. Savart remarks, are of such intensity, that no ear can long support them, and, at the same time, of such a rich and mellow quality, that all other musical Sounds appear poor and harsh in comparison. In order yet more to increase the sensibility of the membrane, the frame on which it is stretched should be fitted over the orifice of a similar resonant cavity. For convenience, and lest the tension of the membrane should vary by hygrometric changes, it is proper to have means of varying this at pleasure, a mode of which is described by M. Savart in the Memoir from which we draw our information. (*Annales de Chimie*, vol. xxiv. p. 76.)

Mode of using a membrane.

334. Vibrations of the air in a chamber examined.

Suppose now that, being provided with such an apparatus as here described, we shut ourselves up in an apartment of regular figure, and free from furniture or projections from the walls, recesses, &c., and place one of our resonant cylinders with its axis horizontal, and the vibrating bell or glass opposite its orifice. In the direction of its axis place the membrane horizontally, with its proper frame and resonant cylinder below it, and strew the horizontal surface with sand. If now, first, we place the membrane thus armed very near the source of the Sound, it will vibrate with great force. As we withdraw it, (keeping it still in the line of the axis of the first resonant cylinder,) its vibrations will diminish gradually, and at length cease, after which (still continuing to remove it along this line) they will recommence and reach a maximum, at a point when their intensity is nearly equal to that close to the source of Sound. Removing the membrane yet further, a new point of indifference is found, and so on till we reach the end of the chamber. If we walk along the same line, keeping the ear in the plane of the horizontal axis of the resonant cylinder, we shall perceive the Sounds to be much louder in the places where the vibrations of the membrane attain their maxima, than at the intermediate points where they are at a minimum. At these latter, a very curious phenomenon has been observed by M. Savart. When the auditor moves his head away from such a point, towards the *right*, (always supposing it to remain in the line of the axis above mentioned,) the Sound will appear to come *from* the *right*, and if towards the left, it will seem to come from the left, whether the original source of Sound be to the one or the other side. This singular effect shows that the aerial molecules on either side of the point of indifference, are in opposite states of motion at any given instant. In making this experiment, the head should be so turned, that the axis of the resonant cylinder prolonged shall pass through both ears. Suppose, for instance, the Sounding apparatus to be to the observer's left, and that his head be very near it. The Sound will appear to enter at his left ear. As he removes further away, so as to pass one of the nodes, it will seem as if the Sound had changed sides, and now came from the right. When another node is passed, it will appear to have again shifted to the left, and so on.

335. Spiral form of the nodal lines in a rectangular chamber, or gallery.

But, if we quit the axis of the cylinder, and carry an exploring membrane, such as already described, about the apartment, noting all the points where it vibrates most forcibly, allowing ourselves, as it were, to be led from spot to spot by its indications, we shall trace out in the air of the room a curve of double curvature marking the maxima of the excursions of the aerial molecules. If the experiment be made in a gallery, or passage, whose length is its principal dimension, this curve will be found to be a kind of spiral, creeping round the walls, floor, and ceiling, obliquely to the axis of the gallery, thus presenting a marked analogy to the disposition of the nodal lines in a long rod vibrating tangentially, (*vide* Art. 313.); which are also, it should be remarked, imitated, with modifications more or less complicated, in square or rectangular rods.

336. Their continuation through a window into the air.

A still more remarkable effect was observed by M. Savart, in thus exploring the vibrations of the air in an apartment with an open window. The spiral disposition of the vibrating portions was found to be continued out of the window into the open air, the lines of greatest intensity running out in great convolutions which seemed to grow wider, on receding from the window, and could be traced to a great distance from it.

337. Vibrations of air in pipes explored by membranes:

The vibrations of the air in an organ-pipe were explored by M. Savart, by lowering into the pipe, placed vertically with its upper end open, a thin membrane stretched on a light ring, and suspended by a fine silk thread, and strewed with sand. Thus ocular demonstration of the existence of its subdivision into distinct ventral segments was obtained, the sand remaining undisturbed when the membrane occupied precisely the place of a node. By this means, too, the influence of the embouchure on the places of the nodes, a curious and delicate point in the theory of pipes, which we have not before alluded to, may be subjected to exact examination. Thus, for instance, when the column of air in the pipe vibrates in the manner described, Art. 190, fig. 19. having two half ventral segments, and one node in the middle, it is found that the node is only approximately so placed, being always, in fact, nearer to the embouchure than to the open end.

338. Resonance of cavities.

It is well known that if we sing near the aperture of a wide-mouthed vessel, some one note (which is in unison with the air in the vessel) will be reinforced and augmented, and sometimes to a great degree. This is what is meant by the *resonance* of the mass of air contained in the cavity of the vessel, or as it may be termed, the resonance of the cavity. This has been known from the earliest times. The ancients are said to have placed large brass jars under the seats of their immense theatres to reinforce (one does not well see how) the voices of the actors. Any vessel or cavity may be made to resound by placing opposite its orifice a vibrating body, having a surface large enough to cover the aperture, or at least to set a considerable portion of the aerial stratum adjacent to it in regular oscillation, and, at the same time, pitched in unison with the note which the cavity would of itself yield. The experiment of the disked tuning-fork, in Art. 204, is a case exactly in point. The pipe which resounds in that experiment, may be pitched precisely in unison with it by its stopper, and in proportion as it departs from a perfect unison the resonance is feebler. A series of disked tuning-forks, or vibrating steel springs, thus placed over the orifices of pipes carefully tuned, constitutes a very pretty musical instrument, capable of a fine swell and fall according as the discs are brought nearer to, or further from, the orifices of the pipes, or inclined to their axes, and of remarkable purity and sweetness of tone. A similar adaptation of resonant cavities to a series of harmonica glasses fixed on a common revolving axis, has been recommended by M. Savart as the principle of a musical instrument, whose effect, should it be found to answer the expectations his description of the tones thus drawn forth is calculated to excite, would probably surpass that of all others yet invented. See Art. 333. The cavities best adapted to this purpose are short cylinders of large diameters with movable bottoms fitting by tight friction by which they may be tuned.

339. Resonance and vibrations of box-shaped cavities. Resonance of cubical boxes.

Such cavities may be regarded as short organ-pipes. When the diameter of a pipe is greatly increased in proportion to its length, so that it becomes *a box*, the law of the proportionality of the time of vibration to the length ceases to hold good, and the note yielded is flatter than that of a narrow pipe of equal length, and the more so the wider the pipe. Thus M. Savart found that a cylinder of $4\frac{1}{2}$ inches in length, and 5 in diameter, resounded in unison with a narrow pipe 6 inches long, making 1024 vibrations per second. That sagacious experimenter has found, that cubical boxes *speak* with surprising promptitude and facility, and yield Sounds extremely pure, and of a peculiar quality, on which account, and by reason of the little height in which they may be *packed*, he recommends them for organ-pipes. A cube of 53 or 54 lines ($= 4\frac{1}{2}^{\text{in.}}$) in the side yields the same note as a pipe 10 or 11 inches long, and 2 or $2\frac{1}{2}$ inches diameter. They may be excited by an embouchure at one of their lower edges, precisely similar to that of an organ-pipe. But they will also speak if the embouchure be situated in the middle of the side. M. Savart has also examined the vibrations of a great variety of different-shaped pipes, boxes, or cavities, for which see *Annales de Chimie*, vol. xxix. p. 404.

340. Communication of vibrations through liquids.

There is yet another remarkable case of vibrations communicated between the different members of a system of which we have not yet spoken, though offering a good example of the verification of the general law of equality of period and parallelism of direction of the vibratory motions of all the molecules of a system laid down in Art. 302. It is when vibrations are communicated through a liquid. The following experiments of M. Savart will show the mode in which this is accomplished.

341. Experiment.

He took a cylindrical tinned iron vessel whose bottom was placed parallel to the horizon, and having cemented to its centre a glass rod, so as to hang perpendicularly down from it, he covered the bottom to the depth of about an inch and a half with water, on which was floated a thin disc of varnished wood, covered on its upper

Communication of normal vibrations.

face with sand. The apparatus thus prepared, he impressed on the glass rod a longitudino-tangential vibration, (Art. 296.) which of course became normal when communicated to the bottom of the vessel, and observed the sand on the upper face of the disc to be also agitated with normal motions, and to assume nodal figures according to the laws of that species of motion. To show more clearly the nature of the communication, he threw out the water, and supported the wooden disc by a small solid stem perpendicular to its surface, and the bottom of the vessel, and attached to the centres of both, when it was found that the disc was affected precisely in the same way as before.

342. Communication of tangential vibrations.

On a vessel of water, whose rim is maintained in a state of normal vibration by a bow drawn perpendicularly across it at any point, let a thin rectangular lamina of wood be floated, having its length parallel to the bow, and its extremity opposite to the point of the circumference excited. The lamina will be seen (as usual by sand strewed on its upper face) to execute longitudino-tangential vibrations, and will be crossed by nodal lines at right angles to its length. But if, instead of directing the axis or longer edges of the lamina perpendicularly towards the vibrating point of the side of the vessel, we incline it obliquely to the direction of the vibrations, still the sand on its upper face will continue to glide in the same direction as before, that is, parallel to the vibrations of the side of the vessel, so that, if the floating lamina be made to revolve slowly in a horizontal plane, the direction of the creeping motion of the sand on its surface will continually vary with respect to the position of its edges, though constant with regard to the sides of the vessel.

343. Communication of vibrations to a body entirely immersed.

Not only are the vibrations thus faithfully transferred through the water to bodies floating on its surface, but even to such as are totally immersed in it. The experiment is easily made by suspending in such a vessel as above described under the water, and not in contact with the sides or bottom, a disc of glass, by means of fine silk threads, and strewing sand on the surface of the water which sinks and spreads evenly on the disc. This will be observed to be agitated with very decided normal, or tangential motions, according as the former or latter of the modes of excitement used in the experiments, Arts. 341, 342, is employed; and to arrange itself in nodal figures accordingly.

344. How we judge of the direction of Sound.

From these and similar experiments it appears that vibratory motions are communicated through liquids precisely as through gases and solids, without change of character or *direction*. This, observes M. Savart, explains how the nerves of hearing, extended throughout the convolutions of the labyrinth and immersed in the liquid which fills it, transmit to the sensorium, not only the general impression of Sound, but of the direction in which it comes.

345. Further analogies between Sound and Light.

These remarkable and striking results all tend to confirm and strengthen the analogy between Sound and Light. The luminiferous ether, like air and liquids, transmits vibrations without altering their direction, as the phenomena of polarized light demonstrate. The additional weight of evidence thus thrown into the scale of the undulatory theory of light did not escape the penetrating mind of Dr. Young, to whom that theory was so deeply indebted. Doubtless the analogy thus ascertained would not have remained idle in his hands, had not death snatched him too from science while in the vigour of his intellect, and when so much might have yet been hoped from him. It has been our unprecedentedly unfortunate lot, while composing these Essays on the sister sciences of Light and Sound, to have to deplore the loss of nearly all the great modern contributors to their advancement. A Frauenhofer, a Fresnel, a Wollaston, and a Young, names forming an epoch in the history of human knowledge, have been snatched away in quick and alarming succession, not enfeebled by age or with faculties weakened by disease, but all in the meridian of their intellectual powers, or in that rich maturity when practice had only familiarized them with their resources, and perfected them in their use. To Dr. Young the theory of Sound is in many respects deeply indebted, and it richly repaid the attention he devoted to it by furnishing him with the pregnant idea of his principle of interferences; a principle which has proved the key of all the more abstruse and puzzling properties of light, and whose establishment would alone have sufficed to place him in the highest rank of scientific immortality, even were his other almost innumerable claims to such distinction disregarded.

Of Light and Sound.

§ III. *Of the Voice.*

346. Almost every animal has a voice or cry peculiar to itself, originating in an apparatus destined for that purpose of more or less complexity. The voice is most perfect and varied in man and in birds, which, however, differ extremely in the degree in which they possess this important gift. In quadrupeds, it is limited to a few uncouth screams, bellowings, and other noises, perfectly unmusical in their character, while in many birds it assumes the form of musical notes of great richness and power, or even of articulate speech. In the human species alone, and that only in some rare instances, we find the power of imitating with the voice every imaginable kind of noise, with a perfect resemblance, and of uttering musical tones of a sweetness and delicacy attainable by no instrument. But in all, without exception, (unless, perhaps, the chirp of the grasshopper, or cricket, be one,) the Sounds of the voice are produced by a *wind instrument*, by the column of air contained in the mouth, throat, and anterior part of the windpipe, set in vibration by the issue of a stream of air from the lungs through a membranous slit in a kind of valve placed in the throat. In man and in quadrupeds, this organ is single, but in birds, as M. Savart has shown, it is double; a valve of the kind abovementioned being placed at the opening of each of the two great branches into which the trachea first divides itself as it enters the lungs, just before they unite into one common windpipe.

The organs of the voice, in man, consist of

347. The thorax.

1. The thorax, which, by the aid of the diaphragm and the 24 intercostal muscles acting on the lungs within, and alternately compressing and dilating them, performs the office of a bellows

348. The trachea and larynx. 2. The trachea, a cartilaginous and elastic pipe which terminates in the lungs by an infinity of roots, or bronchiæ, and whose upper extremity is formed into a species of head called the larynx situated in the throat, composed of five elastic cartilages, of which the uppermost is called the epiglottis, whose office is to open and shut, like a valve, the aperture of the exterior glottis, and which constitutes the orifice of the larynx.

349. The epiglottis. 3. The epiglottis, where it adheres to the larynx, is also united to the tongue, and forms a somewhat concave valve, of a parabolic form, whose base is towards the tongue, and which, by its convexity, resists the pressure of the food and liquids as they pass over it in the act of swallowing.

350. The glottis. 4. Within the larynx, rather above its middle, between the thyroïd and arytenoïd cartilages, are two elastic ligaments like the parchment of a drum slit in the middle, and forming an aperture making a right angle with the exterior glottis, and which is called the interior, or true glottis. This slit, in adults, is about four-fifths of an inch long, and a twelfth of an inch broad. This aperture is provided with muscles which enlarge and contract it at pleasure, and otherwise modify the form of the larynx.

351. The mouth, uvula, &c. 5. The tongue, the cavity of the fauces, the lips, teeth, and palate, with its *velum pendulum*, and the uvula, a pendulous, conical, muscular body, which performs the office of a valve between the throat and nostrils, as well as, perhaps, the cavity of the nostrils themselves, are all concerned in modifying the impulse given to the breath as it issues from the larynx, and producing the various consonants and vowels, according to the different capacities and shapes of their internal cavity.

352. Glottis supposed to act as a reed. In speaking or singing, the glottis, it has been generally supposed, performs the part of a reed. The membranes of which it is composed being kept at a greater or less state of tension by the muscles with which it is provided, and its opening expanded or contracted according to the degree of gravity or acuteness of the Sound to be uttered. But the tone thus originally produced by the glottis is sustained and reinforced by the column of air in the larynx, throat, and mouth, whose dimensions and figure are susceptible of great variation by the action of the innumerable muscles which give motion to this complicated and intricate part of our frame. Thus in a general way we may conceive how the voice is produced and modified; but when we would penetrate further into particulars, the difficulties presented by the organs of the voice are even greater than those which beset the investigation of those of hearing.

353. Difficulty from the gravity of the notes produced. One material one has been lately much elucidated by the experimental researches of M. Savart. How, we may naturally ask, can tones of such gravity as we hear produced by the human voice, be excited in so short a column of air as that contained in the throat of a man? The vibrating column here hardly exceeds a few inches in length, yet the notes produced by a bass singer are those which would require a pipe of several feet in length sounded in the usual manner. That it is not a mere relaxation of the membrane of the glottis is evident; the dropping of the lower jaw, and the effort made in every possible way to increase the dimensions and diminish the tension of the throat and fauces generally, in singing the lower notes of the scale, sufficiently prove that the note of the glottis is reinforced in this case, as in that of acuter Sounds, by the resonance of the cavity in which it sounds.

354. Explained by M. Savart. From M. Savart's experiments it appears that in short pipes, and cavities whose other dimensions bear a considerable ratio to their length, the tone yielded is rendered much graver when the pipe or cavity is constructed of a flexible material capable of being agitated and set in vibration by the air, than when made of more rigid materials. He constructed a cubic box-pipe with paper stretched on slight square frames of wood, joined together at the edges, and made it speak by an embouchure at the edge. He then observed, that so long as the paper was tightly stretched the Sound yielded by the cube was nearly as acute as it would have been had the whole been rigid, but that when its tension was diminished by exposing it to moist vapour, or even by wetting it, the Sound descended in the scale by an interval proportioned to the degree of moisture the paper had imbibed. It was thus lowered even two whole octaves, when it grew so feeble as to be no longer audible; but, repeating the experiment in the still of night, it could yet be heard, and no limit indeed then seemed set to the descent of the Sound; and even when no longer audible the vibration of the paper sides could still be made sensible by sand strewed on them, which arranged itself in nodal lines, for the most part elliptic or circular.

355. Tension and relaxation of the uvula and mouth. The relaxation then, or increase of tension of the soft parts which form the cavity of the mouth and larynx, is no doubt a principal cause of the graduation of its tones. Whoever will sing open-mouthed before a looking-glass will not fail to be struck with the extraordinary contraction of the uvula (a small pendulous substance which seems to hang down from the roof of the mouth) which takes place in the higher notes. It shrinks up almost into a point, and every surrounding part seems to partake its tension.

356. Savart's objections against the reed-like action of the glottis. We have observed that the glottis has been most generally regarded as performing the functions of a reed, especially since the free reed (*anche libre*) invented by Kratzenstein, and revived by Grenié, (probably without knowledge of Kratzenstein's prior invention; *vide* Willis, *Phil. Trans. Camb.* vol. iii.) has been brought into general notice. This idea is strongly advocated among others by Biot. But M. Savart professes himself dissatisfied with such an explanation of its use. He remarks, and seemingly with justice, that the essential principle of a reed, the periodical opening and closing of the orifice through which the stream of air passes, is wanting in the glottis. Were the glottis a reed, the edges of the vocal ligaments which form the slit through which the air passes would require to be almost in contact, and should be alternately forced asunder by the effort of the air, and brought together by their tension. But on the contrary he found that the larynx of the dead subject, when left in its natural state, and gently blown into through the trachea, yielded Sounds approaching to those of the voice, although the opening left between the borders of the glottis was as much as one-sixth, or even one-fourth of an inch across, and more than half an inch long.

357. M. Savart's explanation of the voice. The instrument to which M. Savart attributes the greatest analogy to the larynx, is a species of whistle, common enough as a children's toy or even as a sportsman's call, in the form of a hollow cylinder about three-fourths of an inch in diameter, closed at both ends by flat, circular plates, having holes in their centres. The form is not of

much importance, it may be made hemispherical, &c. Being held between the teeth and lips, the air is blown through it, and Sounds are produced which vary in pitch with the force of the blast. If the air be conducted to it through a *porte vent*, and cautiously graduated, all the Sounds within the compass of a double octave may readily be obtained from it; and if great precautions are taken in the management of the wind, tones even yet graver may be educed, so as to admit, in fact, no limit in this direction.

357. Amman's work on the voice.

When we come to investigate the nature of articulate Sounds, and of speech, the difficulties are much greater. Conrad Amman, in his work on the Voice, first attempted to explain the manner in which the vowels and consonants are formed. With regard to the vowels, he regards them as mere modifications of the continued tone produced by the larynx, depending on the configurations of the mouth. Thus to pronounce A (the broad A in Ah!) the tongue must be laid flat in the lower jaw, and the mouth opened wide, and lips turned outwards. Any musical or continued tone produced in the throat will then have the character of the vowel A. If the tongue be gradually elevated so as to bring its middle nearer the palate, and at the same time thrust forwards, its extremity approaching the upper teeth, the Sound will deviate from the broad A into *a* (hate,) *e* (peep.) These Sounds therefore (the *a* in hate, and the *e* in peep) he calls dental vowels. On the other hand, if, the tongue remaining as before, the lips be thrust out and drawn together, preserving as great an interior cavity of the fauces as possible, we shall have the Sounds of the vowels in *all, hope, poor, wood.* These he calls labial vowels, &c. These distinctions are to a certain extent correct and reasonable, but they give us no insight into the question, *What it is which constitutes the essential distinction between vowel and vowel, and on what part of the mechanism of the voice do vowel Sounds depend?*

358. Kratzenstein's investigation of the vowels.

In 1779, the Imperial Academy of Petersburgh proposed as one of their prize questions, an inquiry into the nature of the vowel sounds A E I O U, and the construction of an instrument capable of artificially imitating them. The prize was awarded to M. Kratzenstein, whose curious Memoir on the subject the reader may find in the XXIst volume of the *Journal de Physique*, p. 358. His principle consisted in the adaptation of a reed in all essential respects similar to Grenié's, where the tongue passes to and fro through the slit without contact, to a set of pipes of peculiar forms, some of them very odd ones, and for whose shapes no other reason could be given than their success on trial. This, however, was a great step. It showed the vowel quality of a Sound to be something distinct from mere *pitch*, and susceptible of being produced at pleasure by mechanical artifice. Pursuing this idea, Mr. Willis has lately entered more extensively into the subject, and, in a Paper recently printed in the IIId volume of the *Transactions of the Cambridge Philosophical Society*, has succeeded in educing all the vowel Sounds by a mere combination of a reed on Kratzenstein's construction with a cylindrical pipe of variable length, and investigating the laws of their production.

359. Remarks on written language

This may be the place to remark the extreme imperfection of our written language in its representation of vowels and consonants. We have six letters which we call vowels, each of which, however, represents a variety of Sounds quite distinct from each other, and while each encroaches on the functions of the rest, a great many very good simple vowels are represented by binary or even ternary combinations. On the other hand, some single vowel letters represent true diphthongs, (as the long sound of *i* in alike, and that of *u* in rebuke,) consisting of two distinct simple vowels pronounced in rapid succession, while, again, most of what we call diphthongs are simple vowels, as bleak, thief, laud, &c. This will render an enumeration of our English elementary Sounds, as they really exist in our language, no matter how written, not irrelevant. We have therefore assembled in the following synoptic table sufficient examples of each to render evident their nature, accompanied with occasional instances of the corresponding Sounds in other languages. The syllables which contain the Sounds intended to be instanced are printed in italics where words of more than one syllable are instanced.

360. Synoptic table of English vowel Sounds.

1. { ¯ Rook; Julius; Rude; Poor; Womb; Wound; *Ou*vrir, (Fr.)
    ˘ Good; Cushion; Cuckoo; Rund, (Germ.); Gusto, (Ital.)
2. Spurt; *Assert;* Dirt; *Vir*tue; Dove; Double; Blood.
3. Hole; Toad.
4. { ¯ All; Caught; *Or*gan; Sought; Broth; Broad.
    ˘ Hot; *Com*ical; *Kom*men, (Germ.)
5. Hard; *Bra*ten, (Germ.); *Char*latan, (Fr.)
6. Laugh; Task.
7. Lamb; Fan; That.
8. Hang; Bang; Twang.
9. Hare; Hair; Heir; Were; Pear; Hi*er*, (Fr.); *Leh*ren, (Germ.)
10. Lame; Tame; Crane; Faint; *Lay*man; Même, (Fr.); *Städ*chen, (Germ.)
11. *Le*mon; Dead; Said; *A*ny; *E*very; Friend; *Be*sser (Germ.); *E*loigner, (Fr.)
12. *Li*ver; Diminish; Persevere; Believe.
13. Peep; *Lea*ve; Bel*ieve;* Sieben, (Germ.); Coquille, (Fr.)
14. s; *s*ibilus; *c*ipher; the last vowel and the first consonant.

True Diphthongs.

361. Diphthongs.

1. Life; The Sounds No. 5 and No. 13, slurred as rapidly as possible, produce our English *i*, which is a real diphthong.
2. Brow; Plough; *Lau*fen, (Germ.) The vowel Sound No. 5 quickly followed by No. 1.
3. Oil; *Käu*en, (Germ.); No. 4 succeeded by No. 13.
4. Re*buke;* Yew; You; No. 13 succeeded by No. 1.
5. Yoke; No. 13 succeeded by No. 3.
6. *Young*; *Yearn*; *Hear*; *Here*; No. 13 succeeded by No. 2 more or less rapidly.

The consonants present equal confusion. They may be generally arranged in three classes: sharp Sounds, flat ones, and indifferent or neutral. The former two having a constant relationship or parallelism to each other, thus:

362. Consonants.

363. Sharp consonants.

Sharp Consonants S. *sell*, *cell*; σ. (as we will here denote it) *shame*, *sure*, *schirm*, (Germ.); θ. thing; F *fright*, *enough*, *phantom*; K. *king*, *coin*, *quiver*; T. *talk*; P. *papa*.

364. Flat.

Flat Consonants. Z. *zenith*; *casement*; ζ. pleas*ure*, *jar*din, (French); ⊟. the *th* in the words *the*, *that*, *thou*,; V. *vile*; G. good; D. *duke*; B. *babe*.

365. Neutral.

Neutral Consonants. L. *lily*; M. *mamma*; N. *Nanny*; ν. hang; to which we may add the nasal N in *gnu*, *Ætna*, *Dnie*per, which, however, is not properly an English Sound. R. *rattle*; H. *hard*.

366. Compound.

Compound Consonants. C, or Tσ. *church*, *cice*rone, (Ital.) and its corresponding flat sound J. or D ζ. *jest*, *gen*der; X. *ex*treme, Xer*xes*; ξ. *ex*asperate, *exalt*, *X*erxes; &c. &c.

367. Remark on an universal alphabet.

We have here a scale of 13 simple vowels and 21 simple consonants, 33 in all, which are the fewest letters with which it is possible to write English. But on the other hand, with the addition of two or three more vowels, and as many consonants, making about 40 characters in all, every known language might probably be effectually reduced to writing, so as to preserve an exact correspondence between the writing and pronunciation; which would be one of the most valuable acquisitions not only to philologists but to mankind, facilitating the intercourse between nations, and laying the foundation of the first step towards a universal language, one of the great desiderata at which mankind ought to aim by common consent.

368. Difficulties of imitating speech by mechanism.

This enumeration will serve to show what are the difficulties which any one must contend with in constructing, what has been often attempted, a *talking engine*. Still the partial success obtained by Kratzenstein, and about the same time by Kempelen, who has given a very curious account of his experiments in *Mécanisme de la Parole*, ought to encourage further trials.

369. Mr. Willis's experiments on the vowel Sounds. Fig. 172. Repetition of Kempelen's experiments. Fig. 173.

To return, however, to Mr. Willis's curious and novel researches. He relates that, having provided an apparatus consisting of a wind-chest, or reservoir, connected with a pair of double bellows, and opening into a *port-vent*, having a free reed, on Kratzenstein's, or Grenié's construction, at its termination, his first object was to verify Kempelen's account of the vowels. He therefore adapted his reed to the bottom of a funnel-shaped circular cavity, open at top, as in fig. 172, which represents a section of the apparatus, and on making the reed speak, and placing his hand in various positions pointed out by Kempelen within the funnel, he obtained the vowels A (No. 5.), E (No. 10.), I (No. 13.), O (No. 3.), U (No. 1.) very distinctly, On using, however, a shallower cavity these positions became unnecessary, and the hand might, he found, be replaced by a flat board slided over the mouth of the cavity; and by using a very shallow funnel, as represented in fig. 173, he succeeded in obtaining the whole series in the order U (No. 1.), O (No. 3.), A (No. 5.), E (No. 10.), I (No. 13.)

370. Mr. Willis's researches on reed pipes of variable length. Fig. 174.

Vowel Sounds appear in regular succession and in cycles.

Being thus led away from Kempelen's experiment, he proceeded to try the effect of adapting to the reed cylindrical tubes, whose length could be varied at pleasure by sliding joints. This was easily accomplished by fixing the reed with its port-vent into the end of a pretty long horizontal pipe coming off from the wind-chest, over which on its outside a tube, open at both ends, was made to slide on leather wrapped round it in the manner of a piston, and capable of being lengthened, by the attachment of pieces of similar tube of its own length, to any extent. He thus describes the results so obtained. Let $abcd$ represent the length of the outer, or sounding pipe, projecting beyond the reed, and take ab, bc, cd, &c. equal to the length of a stopped pipe in unison with the reed employed, that is equal to half the length of the sonorous wave of the reed. If, now, the pipe be drawn out gradually, the tone of the reed, retaining its pitch, first puts on in succession the vowel qualities I E A O U. As the length approaches to ac the same series makes its appearance in an inverted order, as represented in the diagram, then on passing the length ac in direct order again, and so on in cycles, each cycle being merely a repetition of the foregoing, but the vowels becoming less and less distinct in each successive cycle, and the distance of any given vowel from its respective central points a, c, &c. being the same in all the cycles.

371. Law of the lengths of vowel sounding pipes.

If another reed be adapted to the same pipes having a different fundamental Sound or sonorous wave, the same phenomena will be produced, only that the central points of the new cycles will now be at a distance from each other equal to the sonorous wave of the new reed, but the *distances of the several vowel points from the centres of the respective cycles will be the same as before*; so that, generally, if the reed wave $ac = 2a$, and the length of the pipe which first produces any given vowel, from a, be equal to u, the same vowel will be constantly reproduced by a pipe whose length $= 2na \pm v$, n being any whole number.

372. Limits beyond which certain vowels become impossible.

When the pitch of the reed is high, so that the length ac of its wave is less than twice the distance aU corresponding to any vowel, all the vowels beyond that distance become impossible. If, for instance ac be less than $2a$U, but greater than $2a$O, the series will never extend so far as U, but on lengthening the pipe indefinitely the succession of vowels I E A O A E I will be repeated. If, in like manner, still higher notes be taken for the reed, more vowels will be cut off. This, Mr. Willis remarks, is exactly the case with the human voice: female singers being unable to pronounce U and O on the higher notes of their voices. For example, the proper length for a pipe to produce O is that which corresponds to the note C″ two octaves above the middle C of a piano-forte, and beyond this note in singing it will be found impossible to pronounce a distinct O

373.

Cylinders of the same length, or more generally cavities of any figure resounding the same note, give the same vowel when applied to one and the same reed.

374. Table of lengths of vowel pipes.

The following table is given by Mr. Willis as expressing the distances from the central points of the cycles at which the several vowels are produced in inches.

	Vowel Sound according to its place in the Scale. Art. 360.	Example.	Length of Vowel Pipe in inches and decimals.	Piano-forte note corresponding.
I	No. 13.	See	0.38 ?	G^{v}
E	11	Pet (? Pay)	0.6	C^{v}
A	10	Pay (? Pet)	1.0	D^{iv}
	6 or 7	Paa	1.8	F^{iii}
	5	Part	2.2	$D^{ii}\flat$
A°	4	Paw	3.05	$D^{iii}\flat$
O	4	Nought	3.8	G^{ii}
	3	No	4.7	$E^{ii}\flat$
U	2	But	Indefinite.	C^{ii}
	1	Boot		

375. Remarks. On this Table Mr. Willis observes that he does not despair of its completion and extension by future experiments, eventually furnishing Philologists with a correct measure for the shades of difference in the pronunciation of the vowels by different nations. One source of fallacious decision, however, it must be remarked, will subsist in its application, in the effect of contrast, on which much of the difference between vowels depends. Its influence indeed may be traced in the above Table itself. Thus Mr. Willis, assisted, no doubt, by the contrast arising from rapid and frequent transition, has been able, to discriminate between the vowel Sounds yielded by pipes of the lengths 3·05 and 3·8, though the Sounds in the exemplifying words Paw and Nought, which he has chosen, are so closely allied that we confess our own inability to detect any shade of difference, for which reason we have designated them by the same number.*

376. Mr. Willis's experiments on mutual influence of a reed and pipe. Mr. Willis terminates this highly interesting Paper with some curious experiments and remarks on the mutual influence of a reed and a pipe with which it is connected, as also of the port-vent, which conducts the air to it. If a reed be made to sound in a pipe of variable length (l), the Sound yielded by it will remain constant till the length (l) (beginning we will suppose from o) becomes nearly equal to $\frac{a}{4}$, or one quarter the length of the Sound wave of the reed; here it begins to flatten, and as l is still increased, continues to do so till the length somewhat exceeds $\frac{1}{2}a$, when it suddenly jumps back to a note about a quarter of a tone sharper than the original Sound of the reed, to which it, however, soon again descends, and continues stationary till the length l becomes nearly equal to $2a + \frac{1}{4}a$, when the flattening again commences, and continues till l exceeds $2a + \frac{1}{2}a$, and so on periodically, but less decidedly. The total amount of flattening is usually a whole tone. Production of a double note. A jerk of the bellows, or a too hasty lengthening of the pipe, will make the pitch spring back much sooner than it would do with cautious management, nay, with proper dexterity it may be made to yield, just about the point of junction, a double note, composed of one flatter and one sharper than the reed would yield alone. Mr. Willis seems to think that in this case, however, the two Sounds are only quickly alternated so as to seem to go on at once. Examining the reed in a glass pipe with a magnifier, he found its excursions diminished when the note was flattened or sharpened; but when the double Sound was educed they were no longer well defined, but the tongue of the reed seemed thrown into strange convulsions. This recalls the experiment of Biot and Hamel described in Art. 199, 202.

377. Weber and Floss's Work on reed-pipes. Being thus brought back to the subject of reeds and forced vibrations, we must not omit to recommend to our reader's attention the curious and elaborate dissertation of MM. Weber and Floss, entitled *Leges oscillationis oriundæ si duo corpora diversâ celeritate oscillantia ita conjungantur ut oscillare non possint nisi simul et synchronicè exemplo illustratæ* TUBORUM LINGUATORUM. A detailed comparison of their results with those of Mr. Willis, which the necessity of bringing this Essay to a close forbids us to enter into, would be very interesting. MM. Weber and Floss agree with him in the periodical recurrence of the note of the reed at equal intervals, and in its flattening up to a certain point, &c.; while in other points there is diversity of result enough to make a careful revision of the whole subject well worth while; though, perhaps, it is not more than may be accounted for by the different constructions of their reeds; in the one set of experiments the oscillations of the tongue of the reed having been executed parallel, in the other at right angles to the axis of the cylinder. It is somewhat curious, that they seem to have entirely overlooked the vowel quality of the Sounds educed, perhaps from not having employed sliding tubes, and thus missing the effect of contrast.

378. Savart on elasticity of crystallized bodies. We had proposed to have devoted a section to M. Savart's recent elegant application of his delicate methods of detecting and exploring sonorous vibrations to the determination of the law of elasticity in different directions with respect to the axes of crystallized bodies; but it would lead us too far, and we must be content to refer our readers to the XLIId volume of the *Annales de Chimie* for information. The field is a wide one, and it will, we doubt not, be long before it is fully explored.

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* Let the reader pronounce slowly, and distinctly, the words Paw, Gnaw, Naughty, Nought, for his own satisfaction.

Neither shall we devote a separate section to the description and explanation of acoustic phenomena which occur in Nature. Many such, indeed, have been sufficiently noticed already. In Art. 23 we have explained

379. Sound of earthquakes. satisfactorily the origin of thunder, and we shall here only remark that the subterraneous thunder which accompanies earthquakes may (at least in some cases) be ascribed to a general cause not very dissimilar, the successive arrival at the ear of undulations propagated at the same instant from nearer and remoter points, or if from the same points, arriving by different routes, through strata of different elasticities.

380. The concise and unblunted propagation of Sound through water, remarked by Messrs. Colladon and Sturm, is curiously exemplified by the shock of an earthquake felt and heard at sea. The sensation is always described as that of striking on a rock; the Sound as that of grating on a gravelly bottom; none of the hard, rough Sounds of the first impulse being at all softened or *rounded* by the distance.

There is, however, one natural phenomenon so very surprising, and to us, we confess, so utterly inexplicable, though resting on the authority of ear-witnesses of such credit that it is impossible to disbelieve the facts, that we cannot forbear inserting a short description of it, with which we shall conclude.

Description of the place called Nakous.

There is a place about three leagues to the North of Tor, in the neighbourhood of Mount Sinai in Arabia Petræa, called *El Nakous*, (Nakous is the name of a sonorous metal plate used in the Greek convents in the East instead of a bell) from musical Sounds of a very singular and surprising character heard there. It has been visited by very few Europeans, two of whom, however, Mr. Seetzen and Mr. Gray of Oxford, have published accounts of it, the former in the *Monatliche Correspondenz*, (Oct. 1812;) the latter in Dr. Brewster's *Edinburgh Philosophical Journal*, where also Mr. Seetzen's account of it will be found translated, which is as follows:—

"After a quarter of an hour's walking, (from Wody El Nachel?) we reached the foot of a majestic rock of hard sandstone. The mountain was quite bare, and composed entirely of it. I found inscribed on it several Greek and Arabic names, and also some Koptic characters, which showed that the place had been visited for centuries. At noon we reached the part of the mountain called Nakous. There, at the foot of the ridge, we beheld an isolated peaked rock. Upon two sides this mountain presented two surfaces, so inclined, that the white and slightly adhering sand which covers it scarcely supports itself, and slides down with the smallest motion, or when the burning rays of the sun complete the destruction of its feeble cohesion. These two sandy declivities are about 150 feet high. They unite behind the insulated rock, and forming an acute angle, they are covered like the adjacent surfaces with steep rocks, which are mostly composed of a white and friable free-stone.

"The first Sound was heard an hour and a quarter after noon. We climbed with great difficulty as far as the sandy declivity, a height of 70 or 80 feet, and stopped under the rocks where the pilgrims are in the habit of placing themselves to listen. In climbing, I heard the Sound from beneath my knees, and this made me think that the sliding of the sand was the cause, not the effect, of the sonorous motion. At three o'clock the Sound was heard louder, and it lasted six minutes, when, having ceased for ten minutes, it began again. It appeared to me to have the greatest analogy to the humming-top; it rose and fell like the Sound of the Æolian harp. To ascertain the truth of my discovery, I climbed with the utmost difficulty to the highest rocks, and I slid down as fast as I could, and endeavoured, with the help of my hands and feet, to set the sand in motion. This produced an effect so great, and the sand in rolling under me made so loud a noise, that the earth seemed to tremble, and I certainly should have been afraid, had I been ignorant of the cause.

"But how can the motion of the sand produce so striking an effect, and which is, I believe, produced nowhere else? Does the rolling layer of sand act like a fiddle-bow, which, on being rubbed upon a plate of glass, raises and distributes into determinate figures the dust with which the plate is covered? Does the adherent and fixed layer of sand perform the part of the plate of glass, and the neighbouring rocks that of the sounding body? Philosophers must decide this."

We give here M. Seetzen's account in preference to Mr. Gray's as being the earliest, and in his own words, preserving even his own conjectures (not the most plausible) on its cause, and we shall be glad if the visits of future travellers to the spot shall throw further light on this very strange phenomenon.

Slough, Feb. 3, 1830. J. F. W. HERSCHEL.

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END OF VOLUME IV.

ERRATA IN THE ESSAY ON SOUND

Art.	*Line.*	*Error.*	*Correction.*
2,	5,	Hanksbee,	Hauksbee.
2,	15,	Hanksbee,	Hauksbee.
104,	6,	free,	quick and copious.
117,	10,	axes,	positions of the axis.
151,	11,	$x + a t = a$,	$x + a t > a$.
151,	16,	conditon,	condition.
178,	4,	volume,	column.
186,	7, and margin,	fig. 16,	fig. 17.
195,	7,	where,	whose.
209,	10,	times,	terms.
212,	1,	combinations,	combination.
219,	4,	impulse,	impulses.
223,	8,	the extent,	the number, extent.
224,	7,	Sound	sense?
		Nevertheless spiders hear the sound of music. Vide Latreille's anecdote of Pelisson, who tamed one in the Bastille.	
235,	10,	more,	most.
236,	17,	vibrations,	vibrations of the quicker.
238,	3,	figure	figure 31.

ADDITIONAL ERRATA IN THE ESSAY ON LIGHT.

Page.	*Line.*	*Error.*	*Correction.*
416,	19,	α, β, γ,	a, b, c.
434,	5,	organ,	origin.
434,	9,	maxima,	nature.
439,		electric attractions,	elective attractions.
452,	18,	1200,	1100.
456,	18 from bott.	on,	or.
457,	6,	two canals,	dele.
473,	33,	regularly,	irregularly.
518,	35,	mackled,	macled.
518,	11 from bott.	$(x^2 + y^2 + a^2)$,	$(x^2 + y^2 + a^2)^2$.
518,	3 from bott.	holes,	poles.
537,	2 from bott. note,	prelate,	prolate.
541,	12 from bott.	$(B'' v + C'' w) v$	$(B'' v + C'' w) u$.
544,	4,	second plane,	secant plane.
551,	34 from bott.		dele what is said about *camphor*, as that substance in a solid state *does* possess the rotatory property.
556,	7 from bott.	rays,	rings.
557,	6,	rays,	rings.
559,	17,	$\alpha \,.\, \cos O A^2 +$	$y \,.\, \cos O A^2 +$.
560,	17,	$y + y$	$Y + y$.
561,	17,	undulatory,	undulated.
571,	4, col. I,	extra,	extreme.
571,	7, col. 1,		
574,	10,	$\mu \lambda$,	$\lambda \mu$.
577,	5,	hyposulphate of lime and,	dele.

LONDON:
Printed by W. CLOWES,
Stamford-street.